DMcEagle

Volume 22 AUGUST, 1938 Number 8

BULLETIN
of the
American Association *of* Petroleum Geologists

CONTENTS

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OFFICE OF PUBLICATION, 608 WRIGHT BUILDING, TULSA, OKLAHOMA

THE BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS is published by the Association on the 15th of each month. Editorial and publication office, 608 Wright Building, Tulsa,Oklahoma. Post Office Box 979. Cable address, AAPGEOL.

THE SUBSCRIPTION PRICE to non-members of the Association is $15.00 per year (separate numbers, $1.50) prepaid to addresses in the United States. For addresses outside the United States, an additional charge of $0.40 is made on each subscription to cover extra wrapping and handling.

British agent: Thomas Murby & Co., 1 Fleet Lane, Ludgate Circus, London, E. C. 4.

German agent: Max Weg, Inselstrasse 20, Leipzig CI, Germany.

CLAIMS FOR NON-RECEIPT of preceding numbers of THE BULLETIN must be sent Association headquarters within three months of the date of publication in order to be filled gratis.

BACK NUMBERS OF THE BULLETIN, as available, can be ordered from Association headquarters. Paper-bound Vol. 2 (1918), $4.00; Vol. 3 (1919), $5.00. Cloth-bound Vol. 5 (1921), $12.00; Vols. 11 (1927) to 16 (1932), Vols. 18 (1934) to 21 (1937), each $17.00. Other volumes, many separate numbers, and a few nearly complete sets are available. Descriptive price list sent on request. Special prices to members and associates. Discounts to libraries. *Structure of Typical American Oil Fields*, Vol. II (1929), $7.00 ($5.00 to members and associates). *Stratigraphy of Plains of Southern Alberta* (1931), $1.50. *Geology of Natural Gas* (1935), $6.00 ($4.50 to members and associates). *Geology of Tampico Region, Mexico* (1936), $4.50 ($3.50 to members and associates). *Structural Evolution of Southern California* (1936), $2.00. *Gulf Coast Oil Fields* (1936), $4.00 ($3.00 to members and associates). *Comprehensive Index, 1917–1936* (1937), $3.00 (to members and associates: free; extra copy, $2.00).

THE BULLETIN furnishes thirty-five reprints of major papers. Additional reprints and covers for all or part are furnished at cost. ORDERS FOR REPRINTS should accompany corrected galley proof.

Association Headquarters—608 Wright Building, 115 and 117 West Third Street, Tulsa, Oklahoma.

Communications about the Bulletin, manuscripts, editorial matters, subscriptions, special rates to public and university libraries, publications, membership, change of address, advertising rates, and other Association business should be addressed to

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

BOX 979

TULSA, OKLAHOMA

Entered as second-class matter at the Post Office of Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

(Organized at Tulsa, Oklahoma, February 10, 1917, as the Southwestern Association of Petroleum Geologists. Present name adopted, February 16, 1918. Incorporated in Colorado, April 23, 1924. Domesticated in Oklahoma, February 9, 1925.)

OFFICERS FOR THE YEAR ENDING MARCH, 1939

DONALD C. BARTON *President*, Houston, Texas
HAROLD W. HOOTS, *Vice-President*, Glendale, California
IRA H. CRAM, *Secretary-Treasurer*, Tulsa, Oklahoma
WALTER A. VER WIEBE, *Editor*, Wichita, Kansas

(The foregoing officers, together with the *Past-President*, H. B. FUQUA, Fort Worth, Texas, constitute the Executive Committee.)

DISTRICT REPRESENTATIVES

(Representatives terms expire immediately after annual meetings of the years shown in parentheses)

Amarillo: Carl C. Anderson (40), Amarillo, Tex.
Appalachian: Robert W. Clark (39), Pittsburgh, Pa.
Canada: S. E. Slipper (39), Calgary, Canada
Capital: Arthur A. Baker (40), Washington, D. C.
Dallas: P. W. McFarland (40), Dallas, Tex.
East Oklahoma: Frederic A. Bush (39), R. B. Rutledge (39), W. B. Wilson (40), Tulsa, Okla.
Fort Worth: J. F. Hosterman (39), Tulsa, Okla.
Great Lakes: Benjamin F. Hake (39), Indianapolis, Ind.
Houston: Orval L. Brace (39), David Perry Olcott (39), Wallace C. Thompson (40),Houston, Tex.
Mexico: William A. Baker (39), Brownsville, Tex.
New Mexico: Harold S. Cave (39), Roswell, N. Mex.
New York: W. T. Thom, Jr. (39), Princeton, N.J.
Pacific Coast: A. Arthur Curtice (39), Homer J. Steiny (39), E. J. Bartosh (40), Los Angeles, Calif.
Rocky Mountains: J. Harlan Johnson (39), Golden, Colo.
Shreveport: A. F. Crider (39), Shreveport, La.
South America: James A. Tong (39), Caracas, Venezuela
So. Permian Basin: Cary P. Butcher (39), Midland, Tex.
South Texas: Fred P. Shayes (39), Beeville; R. F. Schoolfield (39), San Antonio, Tex.
Tyler: A. C. Wright (39), Tyler, Tex.
West Oklahoma: V. G. Hill (39), Shawnee, Okla.
Wichita: Edward A. Koester (39), Wichita, Kan.
Wichita Falls: Virgil Pettigrew (40), Wichita Falls, Tex.

DIVISION REPRESENTATIVES

Paleontology and Mineralogy

E. H. Sellards (39), Austin, Tex.
Henry V. Howe (39), Baton Rouge, La.

PACIFIC SECTION (Chartered, March, 1925)

W. S. W. KEW, *President*, Standard Oil Company. Los Angeles, California
E. WAYNE GALLIHER, *Secretary-Treasurer*, 930 Petroleum Securities Building, Los Angeles, California
Membership restricted to members of the Association in good standing, residing in Pacific Coast states. Dues: $1.50 per year.

SOUTH TEXAS SECTION (Chartered, April 1929)

W. A. MALEY, *President*, Humble Oil and Refining Company, Corpus Christi, Texas
C. C. MILLER, *Secretary-Treasurer*, The Texas Company, Corpus Christi, Texas
Membership limited to persons eligible to Association membership. Dues: $2.50. Annual meeting in October.

MARACAIBO SECTION (Chartered, April, 1930)

JOHN L. KALB, *President*, Lago Petroleum Corporation, Maracaibo, Venezuela
CHESTER A. BAIRD, *Secretary-Treasurer*, Mene Grande Oil Company, Maracaibo, Venezuela

DIVISION OF PALEONTOLOGY AND MINERALOGY
SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

(Organized, March, 1927; affiliated, March, 1928; chartered, technical division, April, 1930)

E. H. SELLARDS, *President*, Austin, Texas
HENRY V. HOWE, *Secretary-Treasurer*, Louisiana State University, Baton Rouge, Louisiana
SEND DUES, SUBSCRIPTIONS, AND ORDERS FOR BACK NUMBERS TO BOX 979, TULSA, OKLAHOMA.

The Society and the Paleontological Society jointly issue six times a year the *Journal of Paleontology*, Raymond C. Moore, University of Kansas, Lawrence, Kansas, and C. Wythe Cooke, U. S. Geological Survey, Washington, D. C., editors: subscription, $6.00. The *Journal of Sedimentary Petrology*, W. H. Twenhofel, editor, University of Wisconsin, Madison Wisconsin, is issued three times a year: subscription, $3.00. Single copies, *Journal of Paleontology*, $2.00; *Journal of Sedimentary Petrology*, $1.50. Society dues: with *Jour. Pal.*, $6.00; with *Jour. Sed. Petrology*, $3.00; with both, $8.00 per year.

AFFILIATED SOCIETIES

(Dates of affiliation in parentheses)

Alberta Society of Petroleum Geologists, Calgary, Alberta, Can. (31). S. E. Slipper, Secy., 215 Sixth Avenue, West
Appalachian Geological Society, Charleston, W. Virginia (31). Charles Brewer, Jr., Secy., Godfrey L. Cabot, Inc., Box 348
Ardmore Geological Society, Ardmore, Oklahoma (36). J. P. Gill, Secy., Sinclair Prairie Oil Company
Dallas Petroleum Geologists, Dallas, Texas (35). W. W. Clawson, Secy., Magnolia Petroleum Company
East Texas Geological Society, Tyler, Texas (32). C. L. Herold, Secy., Shell Petroleum Corporation
Fort Worth Geological Society, Fort Worth, Texas (31). Herbert H. Bradfield, Secy., The Texas Company
Houston Geological Society, Houston, Texas (32). Lon D. Cartwright, Jr., Secy., Skelly Oil Company
Kansas Geological Society, Wichita, Kansas (31). Forrest E. Wimbish, Secy., 517 North Chautauqua
Michigan Geological Society, Mount Pleasant, Mich. (37). W. A. Clark, Secy., Box 29
North Texas Geological Society, Wichita Falls, Texas (38). Paul E. M. Purcell, Secy., Shell Petroleum Corporation
Oklahoma City Geological Society, Oklahoma City, Oklahoma (31). R. B. Curry, Secy., Carter Oil Company
Panhandle Geological Society, Amarillo, Texas (32). G. R. Carter Secy., Gulf Oil Corporation
Shawnee Geological Society, Shawnee, Oklahoma (31). J. Lawrence Muir, Secy., Amerada Petroleum Corporation
Shreveport Geological Society, Shreveport, Louisiana (32). J. D. Aimer, Secy., Arkansas-Louisiana Gas Company
Society of Exploration Geophysicists, Houston, Tex. (32). H. B. Peacock, Secy., 825 Esperson Building
South Louisiana Geological Society, Lake Charles, La. (37). W. R. Canada, Secy., 207 Weber Building
Southwestern Geological Society, Austin, Texas (37). Hal P. Bybee, Pres., University Lands, Box 1663, Midland ,Tex.
Tulsa Geological Society, Tulsa, Oklahoma (31). L. A. Johnston, Secy., Sunray Oil Company
Western Kentucky Geological Society, Owensboro, Kentucky (38). R. E. Knipe, Secy., The Ohio Oil Company
West Texas Geological Society, Midland, Texas (38). W. C. Fritz, Secy., Skelly Oil Company

Bulletin Advertisers

PROFESSIONAL CARDS

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

Articles for September *Bulletin*

Origin of McMurray Oil Sands, Alberta
By J. C. Sproule

Regional Variations in Composition of Natural Gas in Appalachian Province
By Paul H. Price and A. J. W. Headlee

Geology of Refugio Oil and Gas Field, Refugio County, Texas
By Phil F. Martyn

Origin of Red Sea Depression
By L. Owen

Geological Succession of Central Venezuela
By M. Kamen Kaye

Further Data on Wildcat Drilling in 1937
By Frederic H. Lahee

Behavior of Fluids in Oil Reservoirs
By T. V. Moore

First Geologic Work Fostered by United States Government
By E. H. Finch

Problem of Secondary Tilt—Harker's Solution Corrected
By Emund M. Spieker

Problem of Two Tilts and the Stereographic Projection
By D. Jerome Fisher

Volume 22 Number 8

BULLETIN
of the
AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS

AUGUST, 1938

SOUTH ARKANSAS STRATIGRAPHY WITH EMPHASIS ON THE OLDER COASTAL PLAIN BEDS[1]

WARREN B. WEEKS[2]
El Dorado, Arkansas

ABSTRACT

Deeper drilling and better well records in this area since 1934 have added much to the knowledge of subsurface stratigraphy in southern Arkansas. Wells ranging in depth from 3,000 feet to 8,327 feet have disclosed 4,000 feet or more of sediments below the Travis Peak (Trinity) formation which are generally believed to be Mesozoic in age.

Approximately 1,800 feet of the Eocene series lies unconformably on the Gulf series. The underlying Comanche series of formations includes Fredericksburg, Paluxy, Glen Rose, and Travis Peak. This series, with an aggregate thickness of 4,600 feet in the southwest corner of the state, is completely absent within 85 miles northeast, due to pre-Gulf truncation.

Also truncated at this time, were the underlying 2,250 feet of Cotton Valley formation variegated shales and sands; the 270 feet of Buckner red shale and anhydrite; the 870 feet of Smackover limestone; and the 1,800 feet of Eagle Mills red shale and salt formation. These lower beds are thought to be Mesozoic in age; however, the Eagle Mills may be older.

The underlying Paleozoic formations are steeply folded and are probably a part of the Ouachita Mountain system.

LOCATION

The area discussed comprises that part of southern Arkansas south of T. 6 S., as presented by Figure 1. This is about one fourth of the total area of Arkansas. Except for the extreme northwestern part, the area is in the Gulf Coastal Plain and beds of Eocene age cover most of the surface.

INTRODUCTORY HISTORY

Prior to the year 1935, there had been only six wells drilled below the depth of 4,500 feet in southern Arkansas. Of these six, one had stopped in the Paluxy formation, one in the lower Glen Rose forma-

[1] Read before the Association of New Orleans, March 16, 1938. Manuscript received, June 17, 1938.

[2] District geologist, Phillips Petroleum Company. Acknowledgment is given to members of the Shreveport Geological Society for suggestions in nomenclature, and to C. O. Stark and D. E. Lounsbery of the Phillips Petroleum Company, Bartlesville, Oklahoma, for permission to publish this paper.

tion, three in the Travis Peak formation, and the sixth, the Lion Oil Refining Company's Hayes 9-A, drilled to 7,255 feet in Sec. 4, T. 16 S., R. 14 W., on the Norphlet dome of the Smackover field, had penetrated what was called "Travis Peak," or "Lower Trinity" red series (19),[3] approximately 700 feet of limestone, and 1,300 feet of salt. There was no satisfactory determination of the age of the limestone and salt; however, it was the general belief that the limestone was lowermost Comanche in age and that the salt was Permian in age.

To that time, most of the wells drilled in this area had stopped at depths ranging from 1,500 feet to 3,000 feet, ending in formations of Gulf (Upper Cretaceous) age. A few of these relatively shallow wells in the north and east portions of the area had penetrated into Comanche red beds and older formations. Records on all these wells consisted largely of drillers' logs, many of which were inaccurate as to depth measurements as well as to the formations encountered. These records were supplemented by a relatively few paleontological reports of scattered series of cores. There had been no systematic collection of cuttings and cores from the wells, consequently very little was known as to the character of the formations underlying the Gulf series. Although, there were considerable data accumulated on the upper beds, there had been little material saved which might be used for further first-hand study and comparison.

During the year 1935, three deep tests were drilled in this area. In Sec. 10, T. 17 S., R. 14 W., within the Rainbow City pool (Champagnolle) which was producing from sands in the Travis Peak red beds at 3,000–3,600 feet, H. L. Hunt drilled Gregory No. 15 to a depth of 6,911 feet, 100 feet into the salt. This well cored continuously through the "red-bed" section and a good set of cuttings was obtained through the underlying "lime." Later, the Gulf Refining Company of Louisiana drilled its Louis Werner Saw Mill No. 49, in Sec. 5, T. 16 S., R. 16 W., on the Louann dome of the Smackover field, to a depth of 7,973 feet, having penetrated approximately 700 feet of limestone, 900 feet of salt, and 350 feet of red slates before being abandoned in dark basic igneous rock.

Near the end of the year the Benedum and Trees Corporation drilled its Brigham No. 1, in Sec. 29, T. 14 S., R. 19 W., in southwestern Ouachita County, to 5,245 feet, ending in the basal part of the red-bed section—at that time thought to be the lower part of the Travis Peak formation.

Following the finding of oil production during the summer of 1935 in the lower Glen Rose formation in the Rodessa field in the north-

[3] Figures in parentheses refer to the Bibliography at the end of the article.

western corner of Louisiana, there was an increased interest in the possibilities of production from this formation in southern Arkansas. There were several wildcats drilled into this formation during 1936 and 1937, but no further production was found in the Glen Rose formation of this area until April, 1937. The completion of McClanahan's Capps Brothers No. A-1 in Sec. 11, T. 20 S., R. 28 W., in the Mitchell sandy zone of the Gloyd limestone zone of the lower Glen Rose, extended the Rodessa field into southwestern Arkansas.

Meanwhile, the Phillips Petroleum Company found the first oil production from sub-red-bed limestone in the Reynolds well No. 1 in Sec. 27, T. 15 S, R. 15 W., near Snow Hill in the northern part of the old Smackover field. This well was completed May 8, 1936, producing 40 million cubic feet of gas per day and some distillate.

This production of oil and gas from the deep limestone encouraged prospecting to this depth so that several wells were drilled into this formation. This wildcatting activity has resulted in the finding of four deep oil pools. The Schuler field around Sec. 18, T. 18 S., R. 17 W., produces oil and gas from the Reynolds oölitic zone of the Smackover limestone, oil from the Jones sand immediately above the limestone, and oil from the lenticular sands near the top of the Cotton Valley formation. In Sec. 8, T. 16 S., R. 22 W., the Standard Oil Company of Louisiana has opened the Buckner field, producing oil from the Reynolds oölite. The Magnolia field, discovered by the Kerlyn Oil Company's Barnett No. 1 in Sec. 14, T. 17 S., R. 20 W., produces oil from the Reynolds oölite. The Village field, a very recent discovery by the Standard Oil Company of Louisiana with its Phillips No. 1 in Sec. 15, T. 17 S., R. 19 W., produces oil from the same zone.

These recent discoveries will, no doubt, lead to still more widespread deep drilling in the future. As we enter this new era of deep prospecting in southern Arkansas, it has been thought wise to present a summary of the subsurface stratigraphy of this area, dwelling particularly on the facts brought to light by the more recent deep drilling, and on those problems yet to be solved. The deeper drilling of the past 3 years, with the more up-to-date drilling methods, control of mud fluids, careful catching of well cuttings, and the preservation of cuttings and cores has added much to our knowledge of the pre-Gulf strata of this area.

This discussion is not intended to be a very detailed description of all the strata in this area. It is rather a generalized description to show the nature of the deeper horizons and their general relation to the shallower, better known strata.

General Stratigraphy

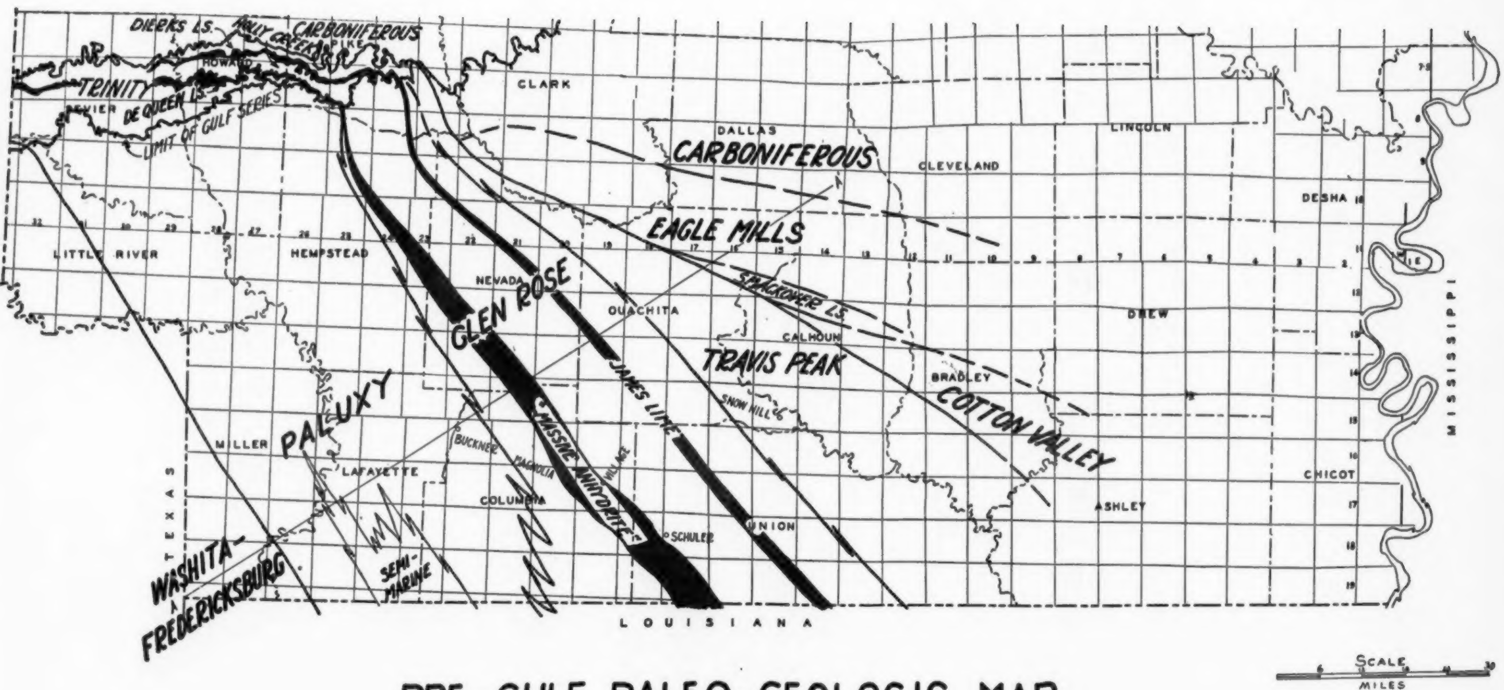
In the Gulf Coastal Plain area of southern Arkansas, we now have some information on an aggregate thickness of nearly 14,000 feet of sediments which are younger than what have been locally referred to as the "basement rocks"; that is, above the relatively closely folded and complex Ouachita Mountain facies of the Paleozoic system. These sedimentary rocks may conveniently be grouped in two main divisions according to their general attitude and extent as well as to the amount of information available regarding their character.

The upper of these two divisions consists of the Eocene series and the Gulf (Upper Cretaceous) series, which, though separated by an unconformity, have much the same attitude and extent. Since these shallower beds were penetrated by wells in earlier drilling and prospecting throughout the area, much information has accumulated as to their stratigraphy. However, there still remain many problems of correlation within these series.

The lower of these two divisions consists of the pre-Gulf formations, which until the past few years had been penetrated in only a few scattered wells and areas. These beds consist of the Comanche series of 4,800 feet, more or less, and the underlying 5,300 feet, more or less, of post-Pennsylvanian rocks which probably have no surface correlatives in this general area. The age of these lower formations is questionable; however, it is now generally agreed that at least part of them are Mesozoic. It is in these little-prospected Comanche beds and the lower newly found formations that we are mostly interested in this discussion. Generalized descriptions of shallower formations are presented only that a view of the relationship of the entire stratigraphic section may be obtained.

The most pronounced subsurface feature of this area, and probably the most important from a stratigraphic standpoint, is the extensive pre-Gulf truncation of the older sedimentary rocks. Thus, 10,000 feet, plus or minus, of rocks in the southwest corner of the state is progressively truncated northeastward so that the entire section is missing within 100 miles, in the southern part of Dallas County.

Figure 1 is a paleogeologic map of the pre-Gulf surface, showing in a very general way the appearance of the beds on the surface prior to the deposition of the Gulf series. Figure 2 is a generalized southwest-northeast geologic section drawn across the strike of the pre-Gulf formations from a point in the southwest corner of the state to a point in Sec. 15, T. 10 S., R. 14 W., in southeastern Dallas County. The section is constructed from data interpolated from the wells in the vicinity of the section. The relationship shown of the lowermost



PRE-GULF PALEO-GEOLOGIC MAP

SHOWING THE GENERALIZED SUBSURFACE DISTRIBUTION OF PRE-GULF STRATA IN SOUTHERN ARKANSAS

DRAWN BY WARREN B. WEEKS

FIG. 1.—Pre-Gulf paleogeologic map, southern Arkansas.

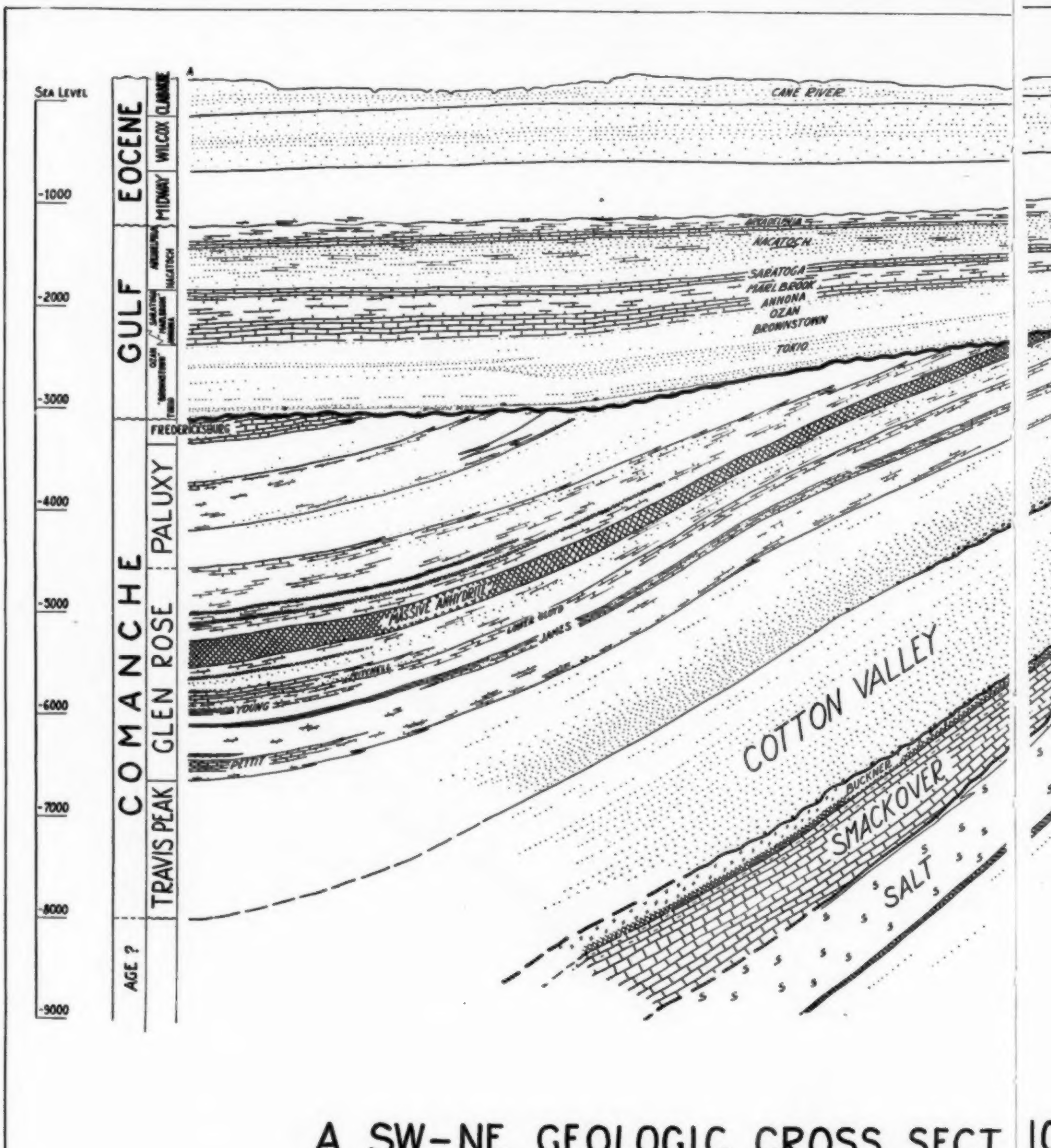
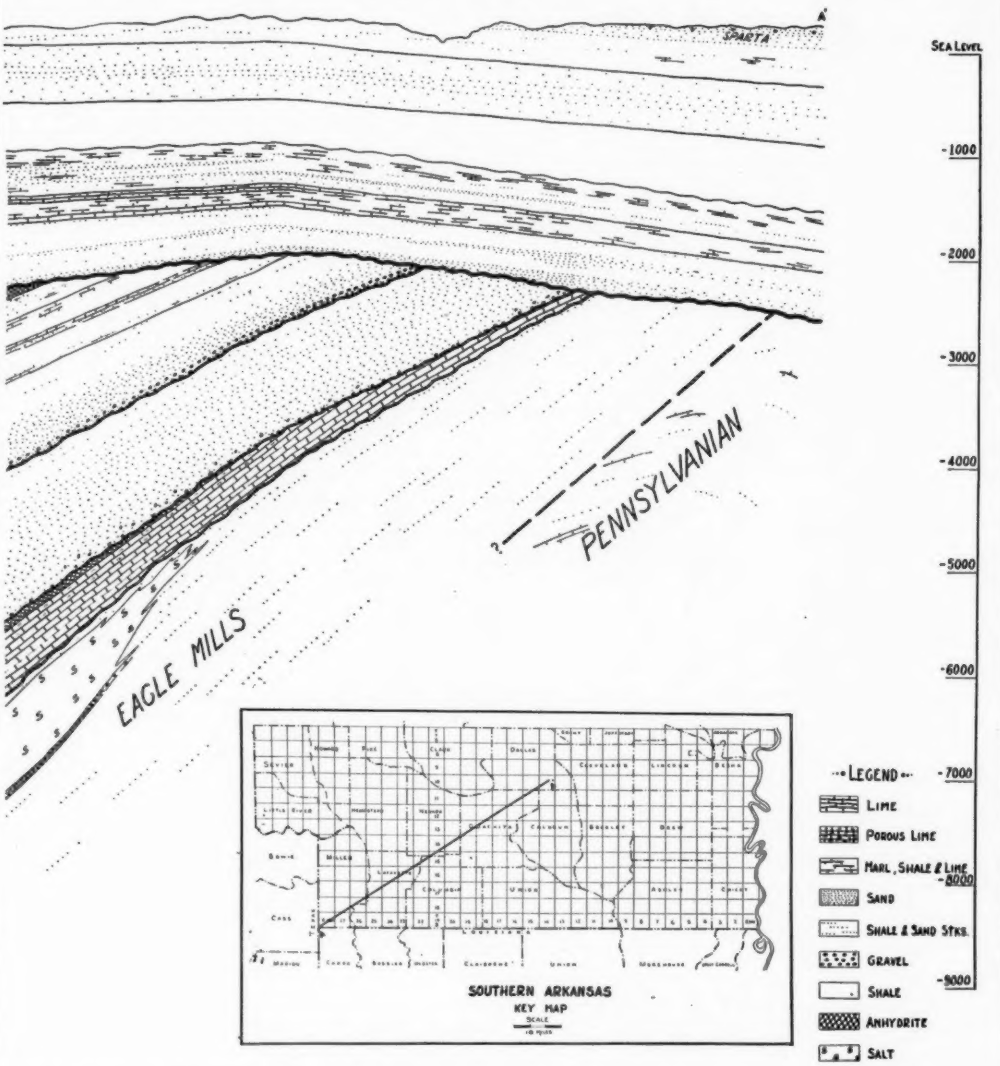


FIG. 2.—Southwest-northeast geologic sec



CT ION IN SOUTHWESTERN ARKANSAS
ULAR TO THE STRIKE OF THE PRE-GULF FORMATIONS
STUD Y OF WELL CUTTINGS BY
REN B. WEEKS

eologic section, southwestern Arkansas.

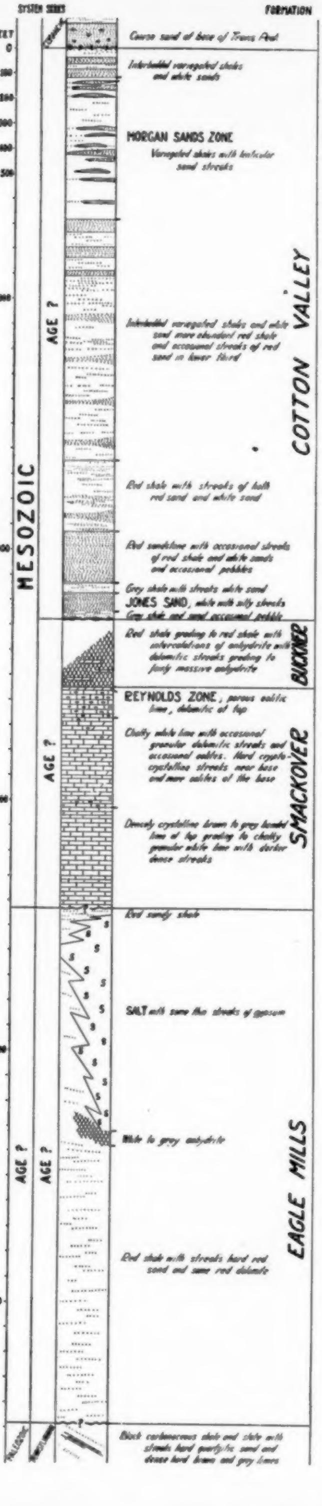


FIG. 3.—Pre-Trinity subsurface strata, southern Arkansas.

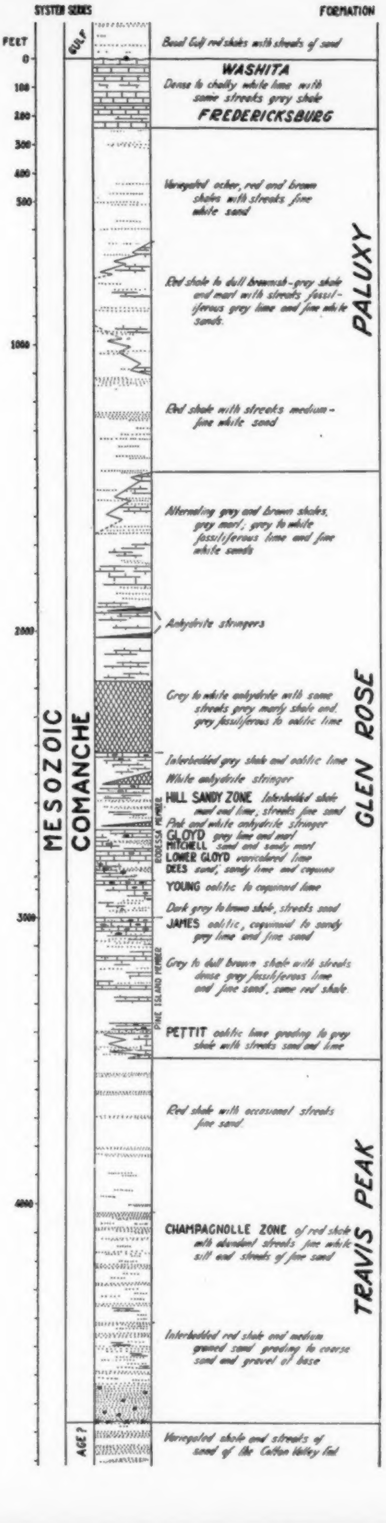


FIG. 4.—Comanche subsurface strata, southern Arkansas.

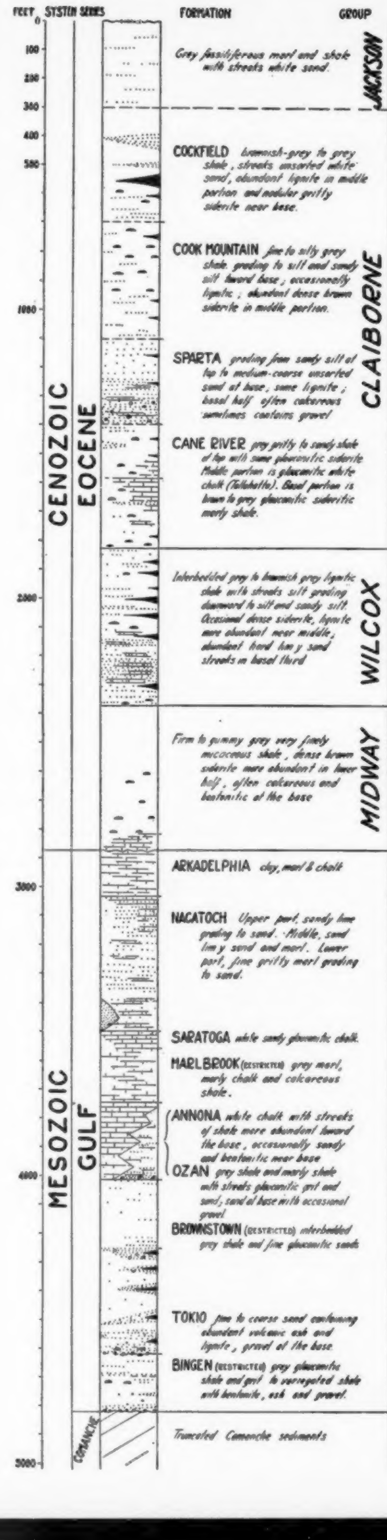


FIG. 5.—Gulf and Eocene subsurface strata, southern Arkansas.

beds, although somewhat hypothetical, seems the most logical interpretation of the present data. Figure 3 is a columnar section showing the nature of the pre-Trinity formations in their maximum known thickness in this area. The stratigraphic sequence of the known Comanche series is indicated in Figure 4, and the younger formations are shown in Figure 5.

Paleozoic System

CARBONIFEROUS

Beds of the Paleozoic system as drilled into below the Mesozoic are only represented to date by Pennsylvanian, and possibly the Mississippian series. At present, there is very little information regarding the correlation of these beds. Representative cuttings from the Paleozoic rocks have been saved from only two or three wells, although beds of that age have been reported in other wells in the northern part of the area.

A well in Sec. 28, T. 11 S., R. 27 W., penetrated 750 feet of hard, tight sand with streaks of black carbonaceous shale. This lithologic character strongly suggests the Jackfork formation (Mississippian) of adjacent southeastern Oklahoma; however, the black carbonaceous nature of the shale streaks may indicate Atoka (Pennsylvanian) formation. Farther east in Sec. 25, T. 9 S., R. 19 W., 610 feet of Paleozoic rocks have been penetrated which consist largely of black carbonaceous shale with streaks of tight, fine sand and some gray to brown limestone streaks. It seems quite probable that these sediments may be in the Atoka formation. A well as far east as Sec. 36, T. 10 S., R. 11 W., penetrated more than 100 feet of tight sand and black shale which might be either Pennsylvanian or Mississippian in age.

Until recently, it had been thought that the thick hard beds of gravel encountered throughout Hempstead and Nevada counties at depths ranging from 2,000 feet to 3,000 feet lay directly on the old "Paleozoic surface." The gravel itself has often been termed the "top of the Paleozoics." Deeper drilling has indicated that this gravel is basal Travis Peak (Trinity), overlapping formations from the Cotton Valley down into the Paleozoic. Thus it remains that the only known subsurface beds of definite Paleozoic age in this region are the hard black slaty carbonaceous shales with their associated tight quartzitic sands and here and there fossiliferous gray-brown limestone streaks.

PERMIAN (?)

EAGLE MILLS FORMATION

Of the 5,300 feet, plus or minus, of strata which lies above defi-

nitely known Paleozoic rocks and beneath the definite Comanche beds, it is quite probable that the lower red beds, salt, and anhydrite are Permian. No definite fauna has been obtained from these beds, although there are vague reports of Permian spores. The very abundance of salt and red-bed sedimentation in the Permian of western parts of Kansas, Oklahoma, and Texas, with no known occurrence of such a salt-red-bed section in any beds of other age in this part of the United States, makes this correlation the most probable. Its relation to other strata is shown in Figure 3.

The Eagle Mills formation is named from the Amerada Petroleum Company's Eagle Mills No. 1, Sec. 11, T. 12 S., R. 16 W., just north of the small lumber town of Eagle Mills in Ouachita County. This well reported 1,190 feet of red shale and sand section. Subsequently other wells were drilled to lesser depths in these red beds and it became known that they had slightly different character from that of the red beds penetrated in the counties south of the Ouachita River.

Farther south, salt was encountered at about the same place in the section and was found to be underlain by similar red shales. It now seems probable that the salt is at least in part equivalent to the red beds.

Thickness and extent.—The record of the thickest section of red beds penetrated in this formation remains the 1,190 feet encountered in the Eagle Mills well. However, there may be several hundred feet more than this in a well in Sec. 14, T. 10 S., R. 20 W. This formation was truncated during pre-Gulf, post-Comanche time so that it is absent within a short distance north of Ouachita County. On the Norphlet dome of the Smackover field, the salt is known to have a thickness of more than 1,325 feet, and at Louann, a short distance west, it is only 850 feet thick. It completely pinches out somewhere between Louann and a well just west of Camden in Sec. 33, T. 13 S., R. 18 W. The red shale has not been penetrated farther south than Sec. 5, T. 16 S., R. 16 W., and the salt has not been drilled into farther south in Arkansas than in Sec. 10, T. 17 S., R. 14 W. The salt was encountered in a well drilled in Caddo Parish, Louisiana, in the Rodessa field south of Miller County, Arkansas.

Character.—The red shale forming the updip and basal portion of the formation is in general harder than the younger red shales of the area and contains only a small amount of greenish gray shale. There are a few streaks of bright red argillaceous sand and more or less nodular streaks of red argillaceous dolomite, which resemble the mudstones of the red Permian beds of western Oklahoma. It is possible that the upper part of the red beds grades to salt basinward, and just

as possible that the salt was deposited in a separate basin subsequent to the deposition of the red beds.

A bed of clear, crystalline, white anhydrite is known at two locations. In the deep well in Sec. 5, T. 16 S., R. 16 W., the salt is separated from the underlying red shale by 60 feet of anhydrite. In a well in Sec. 17, T. 11 S., R. 20 W., in northeastern Nevada County, approximately 100 feet of anhydrite was present separating the Smackover limestone from the underlying Eagle Mills red shales. It is quite logical to correlate these anhydrite beds. It has not been noted in wells farther east where it may be absent by truncation.

The salt at the top of the formation where penetrated is relatively pure crystalline salt with a few seams or partings of white gypsum. It is separated from the overlying Smackover limestone by a 40-foot, plus or minus, bed of red argillaceous sand and sandy shale. No conglomeratic material or other evidence of unconformity has been noted. The break from marine limestone to red beds is abrupt and may denote a hiatus.

Mesozoic System

PRE-COMANCHE BEDS

The upper 3,500 feet of sedimentary formations between definitely Paleozoic rocks and definitely Comanche strata, apparently having no surface correlatives in this region, is tentatively placed in the lower part of the Mesozoic system. Although there has been no definite information published on the fauna, it has been reported to the writer that paleontologists are of the opinion that the meager fauna collected to date represents Mesozoic age. Although these beds are not entirely conformable with the overlying Comanche strata in Arkansas, there is no evidence of unconformity farther south, basinward. The lithologic character of the formations is in some ways very similar to that of the overlying Comanche strata.

This group of formations includes in ascending order the Smackover limestone, Buckner formation, and Cotton Valley formation, as shown in Figure 3.

SMACKOVER LIMESTONE FORMATION

The Smackover limestone has received its name, first used by Bingham (2), from the famous oil pool under which it was first penetrated. It was first known from the Lion Oil Refining Company's Hayes No. 9-A, drilled in Sec. 9, T. 16 S., R. 15 W. There is no direct evidence of an unconformity at the base. The abrupt change to the non-marine Eagle Mills type of lithology may indicate a depositional time break.

Thickness and extent.—The greatest thickness of this limestone formation recorded in Arkansas is 880 feet. In the northern part of the area it very evidently suffered by truncation prior to Cotton Valley deposition and again during the general pre-Gulf hiatus.

The limestone pinches out northward in the vicinity of T. 12 S. The west, east, and south boundaries are as yet undetermined. In Arkansas, the limestone has been found in a well as far west as T. 15 S., R. 26 W., in Miller County; as far east as T. 17 S., R. 9 W., in Ashley County; and as far south as T. 18 S., R. 17 W., in Union County, where it is encountered at a depth of 7,600 feet.

Character.—The lower part of the limestone, comprising 300–450 feet, is gray to brown, dense, crypto-crystalline, banded in many places with carbonaceous argillaceous partings. In the vicinity of Smackover, it may grade to lighter gray, slightly chalky to granular limestone toward the base. Basinward, in the Schuler area in Union County, and in the Rodessa area in the northwestern corner of Louisiana, this basal "dense lime" becomes darker and more argillaceous. To date, 718 feet of Smackover limestone have been penetrated in the Schuler field, slightly more than 200 feet into the "lower dense lime." It is estimated that at least 300 feet more of limestone should be present in that area. A well in the Rodessa area has penetrated 1,230 feet of limestone, of which 740 feet was the lower dense brown to black argillaceous limestone.

The upper 400–500 feet is softer than the lower part. In the Smackover area, where the upper part comprises 400 feet of the total 700 feet of Smackover limestone, the top 100 feet is composed of oölitic, very porous buff limestone. This porous oölitic zone is known as the Reynolds oölite, from the Phillips Petroleum Company's J. D. Reynolds No. 1 in Sec. 27, T. 15 S., R. 15 W., the discovery well in the Snow Hill area and the first well to produce from this zone.

The remainder of the upper part of the limestone is more or less chalky white limestone with varying amounts of disseminated dolomite rhombs. Streaks of hard crypto-crystalline white limestone are plentiful near the base of this zone. In a few places another streak of porous oölitic limestone has been found immediately above the dense limestone.

Southward and basinward, the upper part of this limestone thickens and the chalky limestone is replaced by dense, crypto-crystalline, brown limestone, showing faint oölitic structure at the top, grading to non-oölitic at the base. The entire upper part of oölitic to semi-oölitic limestone comprises 500 feet of section at Schuler and Rodessa.

BUCKNER FORMATION

The Smackover limestone is overlain, apparently conformably, by a formation of anhydrite and red shale which has been referred to as the Buckner formation, because of its presence as a typical section immediately above the productive Reynolds oölite in the Buckner pool of Columbia County. The contact, although definite, does not seem to indicate a time break in sedimentation.

Thickness and extent.—The maximum thickness penetrated in Arkansas is 270 feet. The thickness varies considerably due to truncation during pre-Cotton Valley time. It has been found in wells as far northeast as T. 16 S., R. 14 W. It is probable that it is absent due to regional pre-Cotton Valley truncation northeast of that point. Its west and south limits are not known. It is present as far west as a well drilled in T. 15 S., R. 26 W. Within its areal extent it is absent in some places because of local erosional truncation, as at Schuler. There is some evidence that this formation thickens basinward in northern Louisiana, with anhydrite partly replaced by marine or semi-marine sediments.

Character.—The upper 50 feet of the formation, where present, is red shale with some very finely gritty streaks. Below this, in the same type of red shale are nodules of white to pink finely crystalline (granular) anhydrite increasing with depth and becoming interbedded red shales and anhydrite. The basal 50–60 feet is more or less solid white to pink anhydrite with streaks and partings of red shale. There are some streaks of dolomite and in places the anhydrite is massive and dolomitic. It grades through thin argillaceous dolomite streaks into the Reynolds oölite below.

COTTON VALLEY FORMATION

The name Cotton Valley has been proposed as a formational name to include the group of sands, shale, and limestone which in northern Louisiana has been referred to as the "Lower Marine beds," lying directly below the non-marine Travis Peak. The first production from this formation was in the Cotton Valley field in Webster Parish, Louisiana.

It has become evident that the series of red beds in southern Arkansas above the Smackover limestone and Buckner anhydrite and below the subsurface "Travis Peak" red beds is an updip non-marine phase of the Cotton Valley formation. It was previously thought that these beds were a continuation of the "Travis Peak" red beds, and they were locally called "Lower Travis Peak."

Thickness and extent.—The thickest section of this formation

penetrated to date in southern Arkansas is 2,275 feet in the Schuler field in T. 18 S., R. 17 W., Union County, as shown by Figure 3. In the western part of the area it is overlapped toward the north by the "Travis Peak." It thins within a short distance in that direction due to depositional thinning and probably due to some pre-"Travis Peak" truncation. It is separated by unconformities from both the formations above and below. The marine phase present in Louisiana apparently extends for some distance south, and in that area the unconformities, if present, are not noticeable.

Character.—In the Schuler pool in Union County, the basal portion of this formation consists of the Jones sand which is productive of oil. Named from the the operator who first found production in the sand, the 100-foot sand zone lies on the eroded Reynolds zone of the Smackover limestone. The upper part of the sand is porous and grades to relatively dense calcareous, shaly sand at the base. There are scattered pebbles in the basal few feet. Above the Jones sand is approximately 20 feet of gray shale with tight fine streaks of sand. The Jones sand and overlying shale have not been noticed in any other wells and it is assumed that they are either lenticular or are overlapped updip.

Above the gray shale is a zone of 210 feet of relatively massive fine to coarse red sand with streaks of coarse white sand containing many grains of black chert. The overlying 280 feet of section is similar except that the red shale is predominant and the white sand is more plentiful. Updip, these red sands are at the base of the formation and in many places contain disseminated gravel pebbles of vari-colored chert and quartzite for several hundred feet above the base.

Overlying these predominantly red sections is about 970 feet of variegated red and talc-like gray shales interbedded with many streaks of silt and very fine to coarse white sands. There are a few streaks of red sand in the basal third. Updip, the sand is much more plentiful than the shale.

The foregoing zone is overlain by approximately 570 feet of section which is predominantly light soapy gray shale with intercalations of red shale. The lenticular sands in this zone are productive of oil in the Schuler field and the zone has been named the Morgan sands zone from the Lion Oil Refining Company and the Phillips Petroleum Company's Edna Morgan No. A-1, the discovery well in that pool. The top 10–15 feet of this zone is locally grayish brown glauconitic, slightly fossiliferous shale. To date, this is the only fossiliferous material noted in this formation in Arkansas.

The remaining upper part of the formation consists of approximately 120 feet of interbedded fine sand, siltstone, and variegated talc-like shales in relatively equal proportions.

COMANCHE SERIES

The greatest known thickness of the Comanche series in this area is approximately 4,800 feet. Although some of the underlying beds already described may be Comanche in age, there is no definite information as yet correlating them as such; therefore, they have been excluded in the present writing.

There are some conflicting opinions regarding the nomenclature of the formations within the Trinity group. The subsurface nomenclature in most common usage among the geologists of this area is used in this article with a few exceptions. However, it should be noted that the names and limits of the formations may not exactly coincide with the described correlatives at the outcrops. It is felt that no other new names should be introduced until the exact relationship of the subsurface beds in the Louisiana and Arkansas area to the outcrops in Texas is more satisfactorily determined.

TRINITY GROUP

The Trinity group of formations comprises the largest part of the known Comanche beds of this area. Included in ascending order are the Travis Peak, Glen Rose, and Paluxy formations. As herein used these formations are distinct lithologic units divided as to the marine or non-marine character of the group as a whole. Their limits transgress the definite time-depositional and faunal units.

TRAVIS PEAK FORMATION

In the subsurface terminology of this area the term "Travis Peak" has come to be used to include the basal Trinity section of red beds which are not fossiliferous.

Thickness and extent.—The thickest section of this formation penetrated in southern Arkansas is 1,350 feet in the Schuler pool, Union County. There is a thickness of slightly more than 1,500 feet in the Louisiana Rodessa area.

This formation was truncated during pre-Gulf time so that it pinches out northeastward approximately along the line shown in Figure 1. It pinches out northward by deposition but transgresses up the time section to take the place of part of the Glen Rose beds and is represented on the outcrop in T. 7 and 8 S. by 50–100 feet of gravel and sand, below the Dierks limestone bed of the Glen Rose. The

formation underlies all of the area southwest of these limits and extends into Louisiana and East Texas.

Character.—The basal 350 feet of this formation is composed of interbedded red shales and medium-fine to coarse-grained white sands with here and there nodules of finely granular to dense white dolomite. The basal 100 feet is predominantly sand and contains disseminated very coarse grains of quartz and novaculite and a few small pebbles. Updip, this zone is largely a gravel of vari-colored novaculite and quartzite pebbles and is correlated transgressively with the Pike gravel on the surface.

Above this zone, there is a zone of about 390 feet in thickness composed of red shales with many streaks of fine white silt and fine white sand with some nodules of white dolomite. It is within this zone that the lenticular sands productive in the Champagnolle (Rainbow City) and Urbana pools are found. It is proposed to call this the Champagnolle zone.

The upper part of this formation consists of 540–640 feet of predominantly red shale with a few streaks of white silt and fine sand. This zone grades into, and is in part equivalent to, the Glen Rose formation above.

GLEN ROSE SUB-GROUP

The Glen Rose sub-group is composed of the more or less fossiliferous marine sediments making up the middle part of the Trinity group. This lithologic unit grades into non-fossiliferous red beds both above and below, so that the lower parts of the Glen Rose are the time equivalent of the Travis Peak updip.

The anhydrite zone in the middle part of this sub-group is of importance stratigraphically in that it is an easily recognized consistent marker for subsurface mapping and correlation. The part below the anhydrite zone, usually termed lower Glen Rose, has the economic importance of containing several oil-producing zones.

Thickness and extent.—The Glen Rose sub-group varies considerably in thickness since it grades into the non-marine formations not far northward. It is slightly more than 2,000 feet thick in the southwestern part of the area. It thins in a short distance northward and is represented on the outcrop across T. 8 S. by the interval from the top of the DeQueen limestone to the base of the Dierks limestone. It pinches out by truncation northeast as represented in Figure 1.

Character.—The lower Glen Rose formation, approximately 1,070 feet in thickness, lying between the "Massive anhydrite" and the "Travis Peak," is composed of interbedded gray shales and marls

with streaks of limestone and fine white sand. The limestone and sand beds are apt to be more or less lenticular in nature. They are locally porous and productive of oil in the southern part of Miller County and adjacent areas in Louisiana and Texas. The limestones are ordinarily oölitic, in places coquinoid. In subsurface occurrence, the lower Glen Rose may be divided into two members: the Pine Island member below the Rodessa member. The relative thickness and position of those members is apparent from Figure 4.

The lowermost or Pine Island member, productive in the Pine Island area in Caddo Parish, Louisiana, is represented by a maximum of 500 feet of section in southern Arkansas with the James limestone at the top and the Pettit limestone zone at the base, and with interbedded gray shale, limestone, and sand between them.

The Pettit limestone zone at the base of the member, consisting of more than 100 feet of oölitic limestone in parts of Louisiana, is not well developed where it has been penetrated in southern Arkansas. In this area it is composed of gray shale with streaks of dense gray fossiliferous limestone, and here and there a lenticular sand streak.

The James limestone is the most extensively developed bed of the lower Glen Rose in southern Arkansas. The 100 feet of limestone, sandy limestone, and sand about 575 feet below the "Massive anhydrite" can be recognized in the subsurface in most of southwestern Arkansas. As shown in Figure 1, this limestone apparently is correlative with the Dierks limestone of the outcrop. However, since there may still be some slight doubt of this correlation, the local name of James is retained for this discussion. The name comes from the Arkansas Fuel Oil Company's James No. 1 in Sec. 14, T. 20, N., R. 1 E., Union Parish, Louisiana, where it was first recognized as a distinctive bed by local geologists. In that area it is predominantly calcareous sand rather than sandy limestone.

It is the writer's opinion that the Rodessa member may be correlated directly with the surface Holly Creek unit of Vanderpool (23); however, since there is still some slight doubt regarding this correlation, the more common subsurface term of Rodessa is retained for this discussion. This section between the James limestone and the "Massive anhydrite" includes zones of sand and limestone productive in the Rodessa pool of the Arkansas-Texas-Louisiana corner area. These zones, composed of interbedded limestones, shales, and fine sands, include in ascending order the Young, Dees, Gloyd, and Hill zones and lenses.

The Young limestone lentil, composed of 80 feet, maximum, of porous oölitic to coquinoid limestone in Louisiana, is not well devel-

oped in southern Arkansas, pinching out and grading to interbedded gray shale and dense limestone, and to red shale farther updip.

The Dees sandy zone, lenticular and varying from 10 to 20 feet thick is just above the Young, about 400 feet below the "Massive anhydrite," and, though productive at Rodessa, does not extend far into Arkansas.

The Gloyd limestone zone, immediately above the Dees, is 265–270 feet below the "Massive anhydrite." It is slightly more than 100 feet thick and varies from dense to slightly porous, in places oölitic. It is productive of gas in the Louisiana Rodessa pool, and a sandy zone about the middle, known as the Mitchell sand, is productive of oil on the Arkansas side of the pool. The upper half of the Gloyd limestone grades to shale not far northeastward. The lower half which is glauconitic and vari-colored can be recognized in wells in much of the southwestern part of the state.

Immediately above the Gloyd limestone is a thin lenticular stringer of white to pink anhydrite which probably does not extend more than a few miles into Arkansas. Another anhydrite stringer, 10–30 feet thick, has its base 100 feet below the base of the "Massive anhydrite." It is generally called the "Basal stringer." It probably does not extend more than 12 or 13 miles into Arkansas.

The zone between these stringers of anhydrite is known as the Hill zone. Streaks of sand within this zone are productive in the Rodessa pool. The individual sand members are lenticular and not extensive. However, the sandy zone occurs throughout all of southwestern Arkansas within the limits of the lower Glen Rose. The section between the "Basal stringer" and the "Massive anhydrite" is composed of interbedded gray shales and dense to porous oölitic limestone streaks.

Anhydrite.—The Glen Rose anhydrite, or "Massive anhydrite" member, consists of approximately 250 feet of white finely crystalline anhydrite with streaks and partings of gray shale and dense limestone and dolomite. It is present and limited on the north by the outcrop and on the east as shown in Figure 1 along a line from the outcrop to a point in R. 16 W. at the Arkansas-Louisiana line. Updip, the anhydrite thins to 30 or 40 feet, subsurface, and 10 feet on the surface (15) and changes to white gypsum, present beneath the DeQueen limestone of the outcrop.

Upper Glen Rose.—The upper Glen Rose formation, with a maximum thickness of approximately 730 feet, is composed of gray to dull brown shale and marls with streaks of dense fossiliferous limestone and here and there streaks of fine sand. Two thin anhydrite stringers

are present at 260 and 160 feet, respectively, above the top of the "Massive anhydrite." These stringers pinch out northeastward within 15 or 20 miles from the southwest corner of the state. Practically the entire formation grades to red shales of the Paluxy formation northward, so that on the outcrop only 30–50 feet remains as the DeQueen limestone.

PALUXY FORMATION

The Paluxy formation is a predominantly non-fossiliferous lithologic unit comprising the upper part of the Trinity group and grading abruptly into the Fredericksburg group above.

Thickness and extent.—The Paluxy formation has a maximum thickness of about 1,200 feet exclusive of the thickness gained from the upper Glen Rose updip. It thins near the outcrop, through T. 8 and 9 S., and is limited on the east by pre-Gulf truncation along a line drawn from the outcrop to a point in R. 20 W. along the Arkansas-Louisiana line.

Character.—The formation may be divided into three nearly equal members. The top 400 feet consists of variegated shales and streaks of fine white sand. The middle 460 feet consists of red to dull brownish gray fossiliferous shales with streaks of dense gray fossiliferous limestone and fine white sand. This zone grades into a red shale section within 15 miles north of the state line. The lower 350 feet is composed of red shale with streaks of fine white sand. The entire section becomes more sandy toward the outcrop. Lenticular sands in the upper part of this formation are productive of oil in the Garland City pool, in T. 15 S., R. 26 W., Miller County, where they lie unconformably below "Bingen" sands.

WASHITA AND FREDERICKSBURG GROUPS

Very little subsurface information is available regarding the Washita and Fredericksburg groups in southern Arkansas. In the southwestern corner of the state, they are represented by 240 feet of section composed of dense to chalky white limestone with some streaks of gray shale. It is probable that most of this limestone zone represents the Fredericksburg group. It is limited on the northeast by pre-Gulf truncation along a line as shown in Figure 1 drawn from the SE. corner of T. 20 S., R. 26 W., to the NW. corner of T. 10 S., R. 32 W.

GULF SERIES

The Gulf series as represented subsurface in southern Arkansas can be divided lithologically into three groups. No attempt is made

to name these groups in the present paper; however, the writer feels that it is advisable to point out this logical lithologic grouping which seems more convenient for subsurface work than the carrying over of faunal units from other areas and the outcrop.

The lower group, approximately 800 feet or more in thickness, consists largely of gray finely glauconitic gritty shale with streaks of fine sand. It is locally marly. The lower part in many places has red shales overlain by ash-bearing sands. This group consists of the "Bingen," Tokio, "Brownstown," and Ozan formations, as nearly as present correlations can determine.

The middle group of 150–500 feet consists of white to gray chalk, marl, and shale. In its thickest occurrence, the lower part is equivalent to the Ozan of the outcrop. In general, this group includes the Annona, "Marlbrook," and Saratoga formations.

The upper group comprises a maximum of 600 feet of sands and marl, including the Nacatoch sand formation and the Arkadelphia marl.

It is not the present purpose to go into a detailed description of these formations, or to discuss their correlation with the Upper Cretaceous formations of other areas. The recognizable lithologic units are discussed briefly under the names which are in general usage.

LOWER GROUP

BINGEN FORMATION (RESTRICTED)

The lowest beds in this area in the Gulf series make up a series of interbedded gray to variegated shales and fine to coarse sandstones, containing more or less altered volcanic material. The exact correlation of these beds with the described outcrop of the Gulf series is not certain. In general, they seem to be correlated with that part of the outcrop which Dane (6) describes as Woodbine. However, this formation can not be definitely traced from subsurface to outcrop and the term Bingen, originally used by Veatch (24) as comprising this and the overlying formation, is retained for this discussion.

Thickness and extent.—This formation is present only in the southwestern part of the area. Although it may have been truncated somewhat by subsequent erosion, it is probable that it was not deposited far northeast of the northwest-southeast line drawn through the SE. corner of T. 19 S., R. 13 W. From this line, it thickens westward, being thickest in western Union County, where, besides the ordinary basal variegated shale member (often termed "Tokio reds" or "Upper Cretaceous reds"), it has an upper 70 feet, plus or minus, member com-

posed of finely gritty glauconitic gray shale. The average thickness in most of the area is somewhat less than 100 feet.

Character.—The formation is characterized by its talc-like variegated olive-gray, red and ocherous shales with here and there much green bentonitic clay. Volcanic ash is less plentiful, although present in spots in the shale as well as in sandstones. Some sand grains are coated with greenish gray, ashy, chloritic material. In many places there is a bed of gravel, composed of chert and quartzitic fragments, at the base, and gravel lenses occur in places throughout the formation. In its thickest occurrence, the upper third is gray gritty glauconitic "marine" shale. The formation is overlain and overlapped by the basal ashy sand and gravel of the Tokio formation.

TOKIO FORMATION

The ashy sands originally included as the upper part of Veatch's (24) "Bingen sands" occur subsurface throughout most of southern Arkansas.

Thickness and extent.—There is still some confusion about the correlation of the Tokio of the surface with the subsurface beds. However, there is a section of 150–480 feet, recognized in much of the area, which seems to be correlative with Dane's (6) Tokio of the outcrop. This formation is represented by about 65 feet of section in western Ashley County, but is absent in wells drilled in the eastern part of the county and farther north. It is limited on the north by the outcrop across Sevier and Howard counties and extends southward and westward into Louisiana and Texas. The maximum thickness penetrated is 480 feet in a well in Sec. 36, T. 19 S., R. 26 W.

Character.—The updip Tokio formation is characterized by its sand of medium to coarse grains with a matrix of white volcanic ash, with disseminated chert and quartzite gravel at the base. In most places lignite is plentiful in the sand.

This thickens for a short distance downdip from the outcrop, then gradually thins and loses its ashy characteristic. At its thickest known extent in southern Lafayette County, it is represented by a 30-foot bed of glauconitic sand (Blossom sand). Below it is a section of 450 feet of Tokio comprised largely of gray glauconitic shale with gritty streaks, and lignitic streaks. It has a thin streak of ash-bearing sand at the base.

From that point northeastward toward the Smackover field in Union County, the Tokio formation thins in a short distance, with the younger part transgressively overlapping the older. The sand at the top, on the other hand, thickens and becomes more lignitic and

ashy. At Smackover, the formation is represented by 100 feet of ashy sand.

Little is known regarding the character or extent of the Tokio formation northeast of the Smackover area. There is slight evidence that it thickens somewhat, becoming less lignitic and less ashy.

"BROWNSTOWN" FORMATION (RESTRICTED)

The gray glauconitic gritty shale zone above the lignitic shales of the Tokio and below the pebble-bearing sand zone thought to be basal Ozan is most usually referred to by the term "Brownstown."

Thickness and extent.—The "Brownstown" can not be distinguished from other sub-chalk formations east of central Union County and probably extends no farther east than Bradley and Ashley counties. It is limited on the northwest by the outcrop and extends westward and southward into Texas and Louisiana. It varies in thickness from 150 to 200 feet in most of the area.

Character.—Near the outcrop, the "Brownstown" consists of gray marl with streaks of sand, becoming less marly and more sandy downdip where it is largely gray glauconitic sandy shale.

OZAN FORMATION

The formation above the "Brownstown" has been called Ozan by Dane (5). It was originally included in the Brownstown of Veatch (24).

Thickness and extent.—The reported thickness on the outcrop is 150–250 feet, thinning eastward. South of the outcrop the thickness varies from 250 to 300 feet. It is evidently replaced by the Annona chalk basinward toward Louisiana, so that in southern Lafayette County it is represented by approximately 250 feet of Annona chalk over 50 feet of marl. It is represented by 200 feet of shale and sand at Smackover. It is thinner northeast of Smackover and can not be differentiated from other sub-chalk beds. It is probably overlapped by the Marlbrook on the north and east.

Character.—Near the outcrop, the Ozan consists of calcareous gray shale and gray marl with much grit and glauconite. The base is marked by a very glauconitic sand bed which in many places contains small black novaculite pebbles. This sand, called Buckrange by Dane (6), is present at Smackover as the Graves producing sand. The formation also contains the Meakin and Primm producing sands of Smackover.

Basinward toward Louisiana and Texas, the gritty shales and marls grade into, and are replaced by, white chalk and gray marly chalk. The basal part commonly contains streaks of white bentonite.

MIDDLE GROUP

ANNONA CHALK FORMATION

In part grading into or replacing the Ozan formation and in part overlying it is the Annona chalk.

Thickness and extent.—Dane (6) reports 50 feet of chalk in the western part of the outcrop which thins out almost completely toward the east. The same general relationship exists subsurface. The Annona is represented by only a few feet of section under the area adjacent to the Ouachita River. It thickens appreciably south and west, seemingly at the expense of the underlying Ozan formation. It has a thickness of slightly less than 300 feet in the southwestern corner of the state.

Character.—The Annona chalk is predominantly white massive chalk, having streaks of gray calcareous shale and marl becoming more plentiful toward the base where they grade both laterally and vertically into the Ozan formation. The marls in the basal part commonly contain streaks of white bentonite. The basal stringers of white chalk ordinarily contain some disseminated medium-size grains of glauconite and are commonly sandy.

There is no very distinct break between the Annona chalk and the overlying "Marlbrook" marl. The contact is in places a definite break from gray marl to white or gray chalk; however, in other places it is a gradational change from marl to chalk.

MARLBROOK MARL FORMATION (RESTRICTED)

Dane (6) has restricted the term Marlbrook to the "marl that lies above the Annona chalk or the Ozan formation and below the Saratoga chalk."

Thickness and extent.—Dane (6) gives the Marlbrook a thickness of 50–210 feet westward along the outcrop. In its subsurface extent throughout the southern part of the state, its thickness varies from 150 to 200 feet. Its vertical limits are not well defined throughout most of this area since it grades into, and is not readily distinguishable from, both the Saratago chalk above and the Annona chalk below.

As pointed out by Spooner (18), the Marlbrook marl probably underlies most of the Coastal Plain of Arkansas. It is thinnest in the vicinity of Smackover and along the Ouachita River where it is less than 100 feet thick. It thickens southwest and northeast from that area.

Character.—In most of this area, the Marlbrook marl consists of soft blue-gray calcareous shale and marl. Locally, the gray marl may become relatively pure gray chalk and in this phase is not easily dif-

ferentiated from the overlying Saratoga or underlying Annona. It is more chalky in the extreme southwestern part of the state. It is more argillaceous in the central-southern area. Eastward, into eastern Ashley County, it changes to the sandy limestones and calcareous sands of the Monroe gas rock, where it can not be differentiated from the Nacatoch, Saratoga, and Annona representatives.

SARATOGA CHALK FORMATION

The upper white member of the chalk group was originally placed in the Marlbrook of Hill (10). It has subsequently been called Saratoga by Branner (3). It has been given the status of a definite formation by Dane (6), who says that it lies unconformably on the "Marlbrook marl."

Thickness and extent.—The subsurface thickness of the Saratoga varies little from the reported 20–60 feet (6) on the surface. It has an average and fairly consistent thickness of 60 feet where recognizable. It thins slightly into Miller County. In eastern Ashley County, it can not be differentiated from the remainder of the Cretaceous section. The Saratoga underlies practically all of the Coastal Plain of Arkansas.

Character.—The Saratoga is white to gray hard chalk and marly chalk. It ordinarily contains much fine-grained glauconite throughout its length. It becomes increasingly finely gritty toward the outcrop. Through most of the area, it is the most consistent and easily recognized marker in the Gulf series. Any unconformity below the Saratoga is not readily recognized subsurface.

UPPER GROUP

NACATOCH FORMATION

The Nacatoch sand formation overlying the "Chalk group" was long the most important horizon among the subsurface strata of southern Arkansas since it was the main oil- and gas-producing horizon of the area.

Thickness and extent.—Dane (6) reports outcrop thicknesses from east to west of 150–400 feet. The greatest thickness noted subsurface is in western Miller County where it is 525 feet thick. It thins north and east, being 250 feet thick in the Smackover area. It is 140 feet thick in western Ashley County, and in the eastern part of that county it can not be differentiated from the remainder of the "Gas rock."

Character.—The Nacatoch formation of this area is predominantly sand. In the southwestern part of the state where the formation is thickest, the top consists of from 60–100 feet of hard sandy fossilifer-

ous glauconitic limestone with streaks of medium-coarse sand. Downward the formation grades from medium-coarse calcareous sand and marly sand to a finely gritty marl at the base.

As the formation thins northeast, the limestone pinches to a few feet, and is absent in Union County. The porosity in the middle sandy portion varies considerably. The sand members are lenticular, feathering in and out through the section.

North and east across Union County, the upper lenses of sand pinch out in short distances giving way to gritty marl, and the lower gritty marl becomes more sandy. This lower sand is the main producing zone of the Smackover field. It is probably 100 feet lower in the section than the first Nacatoch sand encountered in the southwestern part of the county.

East of Union County, the marl above the lower sand gradually becomes more calcareous, as does the sand itself, the whole apparently merging into the sandy limestone "Gas rock" of eastern Ashley County.

Northeast of Union County, the section is largely gritty marl with no well developed sands. A similar section was encountered in a well drilled by the Phillips Petroleum Company in Sec. 2, T. 24 N., R. 7 W., Bolivar County, Mississippi, east of Desha County, Arkansas.

Throughout Hempstead and Nevada counties, south of the outcrop, the formation is represented by 300 feet of section. The upper half is calcareous sand, the lower half is finely sandy gray marl.

On the outcrop, Dane (6) reports the Nacatoch as lying unconformably over the Saratoga chalk and unconformably below the Arkadelphia marl. The unconformities, though probably present, are not so evident in the subsurface section, and probably do not extend far into the basin.

ARKADELPHIA MARL FORMATION

According to Dane (6), the name Arkadelphia was first applied to the gray Cretaceous marls above the Nacatoch by Veatch (24), although the name had originally been used by Hill (10) to apply to the upper part of the Nacatoch cropping out near Arkadelphia in Clark County.

Thickness and extent.—The Arkadelphia marl has a reported thickness of 120–160 feet from east to west on the outcrop through Clark and Hempstead counties. The subsurface thickness remains very consistently between 140 and 170 feet throughout the southwestern portion of the state. It thickens to 200 feet in Calhoun and Bradley counties, probably at the expense of the underlying Nacatoch. If it

is present in the eastern part of Ashley County, it is represented by a portion of the "Monroe gas rock." It is probably present under the remainder of the Coastal Plain of this area.

Character.—The general character of the Arkadelphia marl varies little throughout the area. It consists of blue-gray calcareous shale and marl. It is ordinarily more calcareous at the top, and in places there are streaks of white chalk in the upper 40 feet. These streaks of chalk are lenticular and are not characteristic of any area. Some very fine-grained grit and glauconite occur locally in the basal 50 feet.

Cenozoic System

The only Cenozoic beds represented in southern Arkansas are the Eocene series of the Tertiary sub-system and the undifferentiated gravels and loess of the Quaternary. The latter are not within the scope of this paper. The Eocene series is discussed only briefly and very generally, since good records from wells are relatively meager.

Eocene Series

The Eocene series is represented in southern Arkansas by more than 1,800 feet of sedimentary rocks. It may be considerably thicker in the northeastern part of the area. The formational units recognized in other areas are not everywhere easily recognized in the subsurface of this area. This is probably because of the poor records kept through the upper section of most wells. More up-to-date sampling methods should result in more detailed information regarding these formations within the next few years. The present discussion is largely confined to generalized descriptions under the group names in the ascending order of Midway, Wilcox, Claiborne, and Jackson.

MIDWAY GROUP

Spooner (18) gives the Midway formational rank, probably because definite divisions within the Midway group are not easily selected from the well records of this area. Moody (17) used the term Midway group, although he did not attempt any differentiation for this area. Alexander (1) has carried the subdivisions used in Texas into northern Louisiana and southwestern Arkansas.

Thickness and extent.—The thickness of the Midway group varies from 400 to 600 feet with a mean thickness of slightly more than 500 feet in most of the area. The Midway underlies most of the Gulf Coastal Plain of this area; however, it may be absent under some localities in eastern Ashley County.

Character.—In most of the area, the basal part of the Midway

group is referred to as the "Calcareous Midway." It varies from 40 to 60 feet in thickness where known; however, it may be considerably thicker in the northeastern part of the area. This basal calcareous or marly member ordinarily contains streaks of white micaceous bentonite which seem to occur irregularly from top to base. This formation closely resembles the underlying Arkadelphia marl in its lithologic characteristics so that they are not everywhere distinctly separable from the well logs.

The upper remaining part of the Midway is gray clay shale with no very noticeable differences from top to bottom. In general it is slightly more mealy to silty near the top, more gummy near the base. Concretionary siderite is generally plentiful throughout the middle part; however, it may occur through the entire section.

WILCOX GROUP

The term Wilcox was first used by Crider (26) in a description of these beds in Mississippi. Although other names have been applied, Wilcox has come to be most generally used.

Thickness and extent.—The Wilcox group underlies all of southern Arkansas south and east of its outcrop, extending into Texas, Louisiana, and Mississippi. The average thickness of the Wilcox group throughout southwestern Arkansas is about 550 feet; however, it is probably as thick as 800 feet in the southern part of Lafayette County. The thickness in the vicinity of Smackover is approximately 400 feet, and it is nearer 800 feet in eastern Ashley County. It is probably more than 1,000 feet thick farther northeast in Desha County.

Character.—The main characteristics of the Wilcox group are the abundance of fine silt or grit, and the abundance of carbonaceous material. The section is predominantly sandy silt with streaks of sand, lignite, and dark gray to brown lignitic shale. In addition, the basal half is characterized by streaks of gray finely glauconitic calcareous sandstone. There is here and there siderite in the matrix of the calcareous sand. The dark brown shales which are more plentiful toward the top are not everywhere easily distinguished from the overlying Cane River formation.

CLAIBORNE GROUP

The Claiborne group of beds occupies the surface in a large part of southern Arkansas. Although these beds dip beneath the Jackson group in the eastern part of the area, they are still relatively shallow. Since they lie in that part of the section which is drilled very rapidly both in exploration and exploitation operations, it follows that very

little information is available as to the subsurface character of these beds.

Thickness and extent.—Since this group crops out in the western part of the area, the thickness varies considerably according to the surface relief. Farther east, where it is overlain by Jackson, it attains a considerable thickness, somewhat more than 1,500 feet.

Character.—The character of the Claiborne group is best known and inferred chiefly from a few wells drilled recently in Ashley and Bradley counties.

In this area, the basal part, the Cane River formation, is represented by about 400 feet of section. The upper third consists of gray shale and fine silt with a few streaks of fine sand. The middle third consists of white to gray, very glauconitic chalk and marl with a few sandy phases. This member which lithologically resembles the Tallahatta formation of Alabama and Mississippi also contains some concretionary glauconitic siderite which is also present in the basal third of the formation composed of dark gray to brown lignitic and glauconitic shale. The chalk feathers out and is represented by dark gray shale and marly shale west of Ashley County.

Above the Cane River formations lies the Sparta formation, 300 feet more or less of sand and calcareous sand, with considerable gravel in the basal part. The upper part grades to sandy silt and shale toward the west. The section is ordinarily lignitic.

The section above the Sparta consists of the Cook Mountain and Cockfield formations, each approximately 400 feet thick. The lower formation is essentially dark gray, fine to silty shale, grading to sandy silt at the base which resembles the upper part of the Sparta formation. The middle part contains much dark brown dense to granular siderite. The upper formation is similar except that it contains much more lignite.

JACKSON GROUP

Although the Jackson group is present in the eastern part of the area, the outcrops are not extensive, and practically no information is available regarding its subsurface characteristics. In general, it is composed of interbedded sands, shales, and marls.

Conclusion

In considering Figure 1, it becomes evident that most of the northeastward thinning of the Comanche beds is the result of pre-Gulf truncation. The formational thinning takes place more in a northerly or northwesterly direction. It is probable that the boundaries of the

Comanche seas never extended much farther north than the present Trinity outcrop.

The pre-Comanche beds probably suffered some erosion before the Comanche was laid down. The present boundaries of the Cotton Valley seem entirely due to truncation. It is probable that in its original extent it overlapped both the Smackover limestone and the Eagle Mills formations.

Although the northern limitation of the Smackover limestone is due to truncation rather than formational thinning, it seems probable that it never extended much farther north. In its northernmost occurrence, only the top part of the limestone is present, the basal dense part having been overlapped.

From these observations, it may be inferred that there was continually an overlapping of the younger seas onto the deposits of preceding seas from the Eagle Mills time up through Comanche deposition. During the post-Comanche, pre-Gulf interval, there must have been some rather extensive uplift on the northeast, causing a southwestward tilting of these strata. The following extensive erosion left the present truncated condition of these strata.

BIBLIOGRAPHY

1. C. I. Alexander, "Stratigraphy of Midway Group (Eocene) of Southwest Arkansas and Northwest Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 5 (May, 1935), pp. 696–99.
2. D. H. Bingham, "Developments in Arkansas-Louisiana-Texas Area, 1936–1937," *ibid.*, Vol. 21, No. 8 (August, 1937), pp. 1068–73.
3. J. C. Branner, "The Cement Materials of Southwest Arkansas," *Trans. Amer. Inst. Min. Eng.*, Vol. 27, p. 1898.
4. Robert H. Cuyler, "Georgetown Formation of Central Texas and Its Northern Texas Equivalents," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929), pp. 1291–99.
5. C. H. Dane, "Oil Bearing Formations of Southwestern Arkansas," *U. S. Dept. Int. Memo. for Press 8823* (1926).
6. ———, "Upper Cretaceous Formations of Southwestern Arkansas," *Arkansas Geol. Survey Bull. 1* (Little Rock, 1929).
7. Alva Christine Ellisor, "Correlation of the Claiborne of East Texas with the Claiborne of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929), pp. 1335–46.
8. R. T. Hill, "Geology of Parts of Texas, Indian Territory, and Arkansas Adjacent to the Red River," *Bull. Geol. Soc. America*, Vol. 5 (1894).
9. ———, "Geology of the Black and Grand Prairies, Texas," *U. S. Geol. Survey 21st. Ann. Rept.*, Pt. 7 (1901).
10. ———, "The Neozoic Geology of Southwestern Arkansas," *Arkansas Geol. Survey Ann. Rept. for 1888*, Vol. 2 (1888).
11. Henry V. Howe, "Review of Tertiary Stratigraphy of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, No. 6 (June, 1933), pp. 613–55.

12. Merle C. Israelsky, "Correlation of the Brownstown (Restricted) Formation of Arkansas," *ibid.*, Vol. 13, No. 6 (June, 1929), pp. 683–84.
13. ———, "Tentative Foraminiferal Zonation of Subsurface Claiborne of Texas and Louisiana," *ibid.*, Vol. 19, No. 5 (May, 1935), pp. 689–95.
14. Hugh D. Miser and Alexander Deussen, "Review of Tertiary Stratigraphy of Louisiana," *ibid.*, Vol. 17, No. 7 (July, 1933), p. 871.
15. Hugh D. Miser and A. H. Purdue, "Geology of the DeQueen and Caddo Gap Quadrangles, Arkansas," *U. S. Geol. Survey Bull. 808* (1929).
16. Hugh D. Miser and E. H. Sellards, "Pre-Cretaceous Rocks Found in Wells in Gulf Coastal Plain South of Ouachita Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 7 (July, 1931), pp. 801–18.
17. C. L. Moody, "Tertiary History of Region of Sabine Uplift, Louisiana," *ibid.*, Vol. 15, No. 5 (May, 1931), pp. 531–51.
18. W. C. Spooner, "Oil and Gas Geology of the Gulf Coastal Plain in Arkansas," *Arkansas Geol. Survey Bull. 2.* Parke-Harper Printing Company, Little Rock (1935).
19. ———, "Salt in Smackover Field, Union County, Arkansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 6 (June, 1932), pp. 601–08.
20. Lloyd W. Stephenson, "Age of Brownstown Marl of Arkansas," *ibid.*, Vol. 13, No. 8 (August, 1929), pp. 1073–74.
21. ———, "Unconformities in Upper Cretaceous Series of Texas," *ibid.*, Vol. 13, No. 10 (October, 1929), pp. 1323–34.
22. N. L. Thomas and E. M. Rice, "Cretaceous Chalks, Texas and Arkansas," *ibid.*, Vol. 15, No. 8 (August, 1931), pp. 965–66.
23. H. C. Vanderpool, "A Preliminary Study of the Trinity Group in Southwestern Arkansas, Southeastern Oklahoma, and Northern Texas," *ibid.*, Vol. 12, No. 11 (November, 1928), pp. 1069–94.
24. A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46* (1906).
25. E. A. Wendlandt and G. Moses Knebel, "Lower Claiborne of East Texas, with Special Reference to Mount Sylvan Dome and Salt Movements," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929), pp. 1347–75.
26. A. F. Crider, "Geology and Mineral Resources of Mississippi," *U. S. Geol. Survey Bull. 283* (1906), pp. 25–28.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 984-1013, 5 FIGS., 7 PLATES

SUBSURFACE TERTIARY ZONES OF CORRELATION THROUGH MISSISSIPPI, ALABAMA, AND FLORIDA[1]

DONALD W. GRAVELL[2] AND MARCUS A. HANNA[2]
Houston, Texas

ABSTRACT

The Tertiary zones the writers have found to be most useful in subsurface correlation from the Mississippi River to Florida are discussed and the characteristic fossils figured. Fifteen zones, ranging in age from Miocene to Wilcox, are considered. In addition one strike cross section and two dip cross sections are given. Facies changes are discussed in connection with the zones and the cross sections.

INTRODUCTION

As students of structural geology are always faced with the necessity of having accurate time datum planes, the writers are presenting in this paper several zones, their characteristic fossils, and something of their distribution in the Gulf Coast, particularly in the subsurface of Mississippi, Alabama, and Florida. Experience with these zones shows that they have the accuracy required and are marked by an abundance of specimens of large species of foraminifera which have limited vertical range but wide geographical distribution.

These zones are presented because they are excellent and easily recognized zones. Most of them have a relatively wide geographical distribution through Mississippi, Alabama, and Florida irrespective of lateral variation in the character of the sedimentary section. Where several formational names are used for approximately equivalently aged beds between the Mississippi River and Florida, a single zone name is sufficient. Consequently the interpretation of contour points and contouring is greatly simplified, because the variation in the interpretation of formational names and their ages is eliminated.

Several characteristic fossils of the zones have been figured with the belief that they will help those not acquainted with the fossils to recognize the zones. Most of the species have been previously described and figured but the descriptions and figures are scattered through several publications. The faunal succession of many of these larger foraminifera has not been clear heretofore because the type localities are widely scattered and various formational names have been used. Within the eastern Gulf Coast area the succession is becoming clear and correlation with short-range fossil species over wide

[1] Read before the Association at New Orleans, March 16, 1938. Manuscript received, March 30, 1938. Published with permission of the Gulf Oil Corporation.

[2] Paleontologists, Gulf Oil Corporation.

areas is possible. There are a number of species of larger foraminifera not described herein, because to date sufficient data have not been accumulated definitely to place their ranges, but study is progressing.

Samples from the wells shown on the three cross sections have been distributed and have been, or are being, examined by many of the interested oil companies The sections are given chiefly for the purpose of enabling the paleontologists who have examined the samples but who are not acquainted with larger foraminifera to know where the larger foraminifera are found and to help them in recognizing these fossils in future wells.

ZONATION

Subsurface correlation in the Gulf Coast based on detailed paleontological zonation began in the early 1920's. As the result of active exploration for petroleum in Texas and Lousiana these detailed studies were confined largely to the western part of the Gulf Coast. At the same time reconnaissance geological exploration, particularly by the United States Geological Survey, was being carried on throughout the eastern Gulf Coast as well as in the West Indies and Mexico. Because this reconnaissance work was confined to the surface the localities from which fossils were described were scattered and the exact faunal succession was not precisely determined in many places, or at least not so recorded in the literature. From this early reconnaissance work many of the species used in this paper were described by Cushman, Vaughan, and others.

The early zonation in Texas and Louisiana developed almost entirely along the lines of smaller foraminifera, chiefly because of the character of the sediments, the abundance of smaller foraminifera, and the general scarcity of larger foraminifera. *Heterostegina*[3] was the one early exception. In this area the samples from wells disintegrate easily and provide many well preserved smaller foraminifera for study. Recently larger foraminifera have been described from the Tertiary of Texas and Louisiana and other species are in the process of description.

East of the Mississippi River the lithological character of the sediments is in part limestone, whereas in Texas and Louisiana the equivalent sediments are shales and sandstones. From these hard marls and limestones the smaller foraminifera are commonly difficult of extraction and the faunas somewhat different due to ecological conditions. Fortunately these marls and limestones contain an abun-

[3] Esther Richards Applin, Alva C. Ellisor, and Hedwig T. Kniker, "Subsurface Stratigraphy of the Coastal Plain of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 1 (1925), pp. 79-122.

dance of larger foraminifera many of which have relatively short stratigraphic but wide geographic range, making them excellent for zone markers. Several of the species present were described from Texas and Louisiana and they are continuous in the subsurface from Texas to Florida. In cuttings there is ordinarily much sand from higher in the hole which makes it difficult in many places to determine the first of the smaller foraminifera markers. In many of the beds the induration and cementation make freeing of smaller foraminifera almost impossible. In much of the limestone of this area the smaller foraminifera are badly preserved or destroyed through leaching and recrystallization. In contrast the larger foraminifera are ordinarily well preserved and fortunately are strategically distributed throughout the section. In addition in this area the larger foraminifera are known to have very short range as compared with the range of many of the smaller foraminifera which have been used as zone markers in the Gulf Coast. Because of these conditions the larger foraminifera can be used more satisfactorily than the smaller foraminifera as zone fossils in the Gulf Coast east of the Mississippi River.

On the basis of these zones of larger foraminifera contour maps have been constructed of the area from Texas to Florida. It is not implied that smaller foraminifera, ostracoda, bryozoa, *et cetera* are not of value in the Gulf Coast east of the Mississippi River. They can be used with accuracy; however, when one considers the time involved, the uncertainty in some indurated and cemented formations, and the ecologic changes from place to place, it is found that contour maps using the first appearance of the zones described herein, more easily provide for the accuracy needed through the area.

In the western Gulf Coast area zones are used for subsurface correlation almost to the complete exclusion of formational names. This has become necessary because of the multiplicity of formational names, the confusion resulting from the use of different formational names for equivalent beds, and the frequent variation in the interpretation of the upper and lower limits of formations. A similar multiplicity of names exists east of the Mississippi River. Much future confusion can be eliminated there, by the use of zones rather than formational names. In addition, some of the zones can be traced throughout the Gulf Coast. Such a use of zones makes possible a uniformity in contouring which can not be attained through the use of formational names. A zone is usually determined by the fauna found in samples, and then a formational name is assigned. For subsurface correlation and contouring to show structural conditions, there ap-

GROUPS	FORMATIONS	SOME LARGER FORAMINIFERA WHICH ARE CONTINOUSFROM TEXAS TO FLORIDA	ZONES:- MISSISSIPPI, ALABAMA, FLORIDA FIRST APPEARANCE IN WELLS	SOME CHARACTERISTIC SPECIES OF ZONES MISSISSIPPI, ALABAMA, FLORIDA	REMARKS:- MISSISSIPPI, ALABAMA, FLORIDA.
	Oakville		Amphistegina	Amphistegina Sp.	Present Down dip.
Calahoula Restricted	Not Named	Miogypsina (Several Species) Heterostegina israelskyi Heterostegina texana.	Miogypsina- Heterostegina	Miogypsina (Several Species) Heterostegina israelskyi Gravell and Hanna. Heterostegina texana Gravell and Hanna	Characteristic fossils not well developed at outcrop. Extends as well developed zone westward across Louisiana and Texas.
Limestone Creek	Frio *; Chickasawhay; Bucatunna		Lepidocyclina (Eulepidina)	Lepidocyclina (Eulepidina) favosa Cushman Lepidocyclina (Eulepidina) undosa Cushman	Characteristic larger foraminifera not well developed west of the Mississippi River.
Vicksburg	Vicksburg; Byram; Glendon; Marianna		Lepidocyclina supera. Lepidocyclina mantelli.	Lepidocyclina (Lepidocyclina) supera (Conrad) Lepidocyclina (Lepidocyclina) mantelli (Morton)	Lepidocyclina supera and L. mantelli present in Louisiana but western limit of species not known.
Red Bluff	Forest Hill; Red Bluff				
Jackson	Fayette; McElroy; Yazoo; Ocala		Discocyclina (Asterocyclina)	Discocyclina (Asterocyclina) several Species Operculinoides ocalana (Cushman) Operculinoides wilcoxi (Heilprin) Heterostegina ocalana Cushman	Western limit of characteristic larger foraminifera not known in Louisiana. Have been found on one Salt Dome in Texas.
			Operculina mariannensis	Operculina mariannensis Vaughan	Not well developed west of Mississippi River.
	Caddell; Moody Branch	Camerina jacksonensis Camerina moodybranchensis Operculina vaughani Lepidocyclina (Lepidocyclina) mortoni	Camerina jacksonensis	Camerina jacksonensis Gravell and Hanna Camerina moodybranchensis Gravell and Hanna Operculina vaughani Cushman Discocyclina flintensis (Cushman) Lepidocyclina (Lepidocyclina) mortoni Cushman	Characteristic of Moody Branch. Well developed across Louisiana and eastern Texas.
Claiborne	Cockfield; Yegua		Nonionella cockfieldensis Eponides yeguaensis Ceratobulimina eximia	Nonionella cockfieldensis Cushman and Ellisor Eponides yeguaensis Weinzierl and Applin Ceratobulimina eximia (Rzehak)	These zones are very good west of the Mississippi River but have been found to be of less value east of the Mississippi.
	Cook Mountain		Camerina (large)	Camerina (large - at least two species)	Western limit of these species not known.
		Lepidocyclina (Polylepidina) gardnerae Discocyclina perpusilla	Lepidocyclina (Polylepidina)	Lepidocyclina (Polylepidina) gardnerae Cole Discocyclina perpusilla Vaughan	Extends as well developed zone across Louisiana and Texas.
	Sparta; Weches	Discocyclina advena	Discocyclina advena	Discocyclina advena (Cushman)	Extends as well developed zone across Louisiana and Texas.
	Queen City; Reklaw				
Wilcox			Discocyclina blanpiedi - D. cookei	Discocyclina blanpiedi Vaughan Discocyclina cookei Vaughan	Characteristic of Salt Mountain. Western limit of species not known.

* Exact correlation of Mississippi section from Chickasawhay to Red Bluff with Texas section from Frio to Vicksburg has not been determined precisely. It is believed that Lepidocyclina recently found at the top of the Texas "Vicksburg" section will ultimately assist in the solution of the correlation problem.

FIG. 1.—Chart showing general sequence of groups, formations, and zones. Drafting by O. D. Feland, Gulf Oil Corporation, Houston, Texas.

pears to be no good reason for determining the zone and then translating it into the formational name which fits the particular area.

CORRELATION

In the present paper the writers are making no attempt to place the Gulf Coast formations in the Eocene, Oligocene, Miocene, and Pliocene. The type localities of these are in Europe. As is recognized by all geologists the placing of a Gulf Coast formation in any of these units would mean that the formation is definitely of the same age. It must not be forgotten that the type locality of the Miocene is not in Florida, or the type locality of the Oligocene in Antigua. Both are in Europe. Precise correlation with the European standard section is an ultimatc goal, but it is to be remembered that even the geologists of Europe are not in agreement concerning which of certain of their formations are Oligocene and which are Miocene.[4] It is, therefore, not surprising that there is great diversity of opinion among Gulf Coast geologists as to which formations are Oligocene and which are Miocene.

It is true the correlation of certain Gulf Coast formations is not entirely evident, due to depositional variation and resulting faunal differences. Fortunately, however, there is little difference of opinion concerning the sequence of most of the beds in the Gulf Coast (Fig. 1).

It is unfortunate that a diversity of opinion exists regarding which beds are Miocene and which are Oligocene since these two terms have been used extensively by the petroleum industry. Many published records pertaining to production and reserves are based on the Oligocene-Miocene contact being above the *Heterostegina* zone and not at the top of the Vicksburg. These terms will continue in use since they are established in the records of the petroleum industry. A shifting of this contact as one or the other school of thought dictates can cause only confusion. The problem itself cannot be settled until the problem is settled in Europe, and until the Gulf Coast section can be precisely correlated with that of Europe. Even when precise correlation seems established with one group of fossils, it may not be with another group of fossils. It is believed the goal will not be reached for many years to come.

The writers admit without embarrassment that they do not know which beds in Europe are Miocene and which are Oligocene, and they feel equally certain that other students of Gulf Coast geology are in a similar quandary. Until the question of European correlation is

[4] Hubert G. Schenck, "What Is the Vaqueros Formation of California and Is It Oligocene?" *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 4 (1935), pp. 521–36.

settled to the satisfaction of all, the abandoning of the terms Eocene, Oligocene, Miocene, and Pliocene when referring to Gulf Coast geology might be advisable. Since it seems doubtful that this will be done, in the interest of harmony from the viewpoint of the petroleum industry as well as the diversity of opinion regarding correlation, it is believed the paragraph published recently is satisfactory.

> If the terms Miocene and Oligocene must be used in the Gulf Coast, we believe it more logical to consider the *Heterostegina* zone and associated beds, the Chickasawhay and associated beds, and the Vicksburg and associated beds as Oligocene, rather than a part Oligocene and a part Miocene. At the same time we welcome any additional information that will aid in definite establishment of this contact. Until sufficient opposing evidence is presented, we believe it best to follow established usage and consider the *Heterostegina* zone as a part of the Oligocene.[5]

ZONES

AMPHISTEGINA ZONE

Only in the more coastward beds are fossils found above the *Miogypsina-Heterostegina* zone. In some wells a few fossils are found immediately above the first appearance of *Miogypsina* and *Heterostegina* but these are not treated as a separate zone. Only the marine beds above these are considered separately. The value of the higher zones, their exact correlation with surface type sections, and their geographical distribution are not known. Within the area under discussion any one of several fossils might have been used to designate these higher marine beds. *Amphistegina* sp. (Pl. 1, Figs. 1–2) was chosen because of its size and abundance. Several species of *Amphistegina* have been described from the younger beds of the Gulf Coast, but the great variation within any species of *Amphistegina* renders specific identification uncertain in many cases. *Amphistegina*, when found in well samples, is cited as a zone fossil, but at the same time it is recognized that its value will depend on future information. The writers have recorded *Amphistegina* in several wells east of the Mississippi River and in many wells west of the Mississippi.

MIOGYPSINA-HETEROSTEGINA ZONE

This is one of the most important zones of correlation in the Gulf Coast. It has not been definitely recognized at the surface but is traceable in the subsurface from southwest Texas to Alabama. Its correlative in Florida is problematical. In different areas the lithological character of this zone varies. Through Mississippi and Ala-

[5] Donald W. Gravell and Marcus A. Hanna, *Jour. Paleon.*, Vol. 11, No. 6 (1937), p. 522.

bama the material is chiefly limestone, some of which is highly recrystallized. Minor amounts of marl, sandy limestone, shale, and sand are present. West of the Mississippi River shales and sandstones predominate, although marls and limestones occur, particularly around some of the salt domes.

Miogypsina and *Heterostegina* are found through a section of possibly 200 feet in Mississippi and Alabama. It is impossible to determine the exact thickness of the zone in wells from the examination of cuttings because material from above is present. Few wells have been cored continuously. In Texas and Louisiana the section containing *Miogypsina* (Pl. 1, Figs. 6–7) and *Heterostegina* attains a much greater thickness, particularly in the downdip phases.

In addition to several species of *Miogypsina*, *Heterostegina israelskyi* Gravell and Hanna[6] (Pl. 1, Figs. 3 and 11), and *Heterostegina texana* Gravell and Hanna[7] (Pl. 1, Figs. 4–5 and 10), *Lepidocyclina* (*Lepido-*

[6] Donald W. Gravell and Marcus A. Hanna, *Jour. Paleon.*, Vol. 11, No. 6 (1937), pp. 524–25, Pl. 62, Figs. 1–4.

[7] *Ibid.*, pp. 525–26, Pl. 63, Figs. 1–4.

EXPLANATION OF PLATE 1

FIG. 1.—*Amphistegina* sp. Dorsal view, ×17.8. From Gulf Refining Company of Louisiana's Dantzler Lumber Company No. 5, Sec. 32, T. 7 S., R. 6 W., Jackson County, Mississippi. From top of core from 3,123–29 feet.

FIG. 2.—*Amphistegina* sp. Ventral view, ×17.8. From same locality as Figure 1.

FIG. 3.—*Heterostegina israelskyi* Gravell and Hanna. Surface view, ×18. Syntype after Gravell and Hanna. Donald W. Gravell and Marcus A. Hanna, "The *Lepidocyclina texana* Horizon in the *Heterostegina* Zone, Upper Oligocene, of Texas and Louisiana," *Jour. Paleon.*, Vol. 11, No. 6 (1937), Pl. 62, Fig. 4.

FIG. 4.—*Heterostegina texana* Gravell and Hanna. Equatorial thin section, ×18. Syntype after Gravell and Hanna. *Ibid.*, Pl. 63, Fig. 1.

FIG. 5.—*Heterostegina texana* Gravell and Hanna. Surface view, ×18. Syntype after Gravell and Hanna. *Ibid.*, Pl. 63, Fig. 2.

FIG. 6.—*Miogypsina* sp. Surface view, ×18. From cuttings from 1,830 feet in Gulf Refining Company of Louisiana's Pascagoula Lumber Company No. 2, Sec. 15, T. 3 S., R. 7 W., George County, Mississippi.

FIG. 7.—*Miogypsina* sp. Half section through equatorial layer, ×18. Same specimen as shown in Figure 6.

FIG. 8.—*Lepidocyclina* (*Lepidocyclina*) *supera* (Conrad). Equatorial thin section, ×17.8. From under wagon bridge over Pearl River, Byram, Mississippi.

FIG. 9.—*Lepidocyclina* (*Eulepidina*) *undosa* Cushman. Surface view, ×4.31. From 55 feet above Limestone Creek at the side of Highway 45, about ¼ mile east of bridge over Limestone Creek on this highway. Sec. 25, T. 9 N., R. 7 W., Wayne County, Mississippi.

FIG. 10.—*Heterostegina texana* Gravell and Hanna. Vertical thin section, ×17.8. Syntype after Gravell and Hanna. *Ibid.*, Pl. 63, Fig. 3.

FIG. 11.—*Heterostegina israelskyi* Gravell and Hanna. Vertical thin section, ×50. Syntype after Gravell and Hanna. *Ibid.*, Pl. 62, Fig. 2.

FIG. 12.—*Lepidocyclina* (*Lepidocyclina*) *supera* (Conrad). Surface view, ×17.8. From same locality as Figure 8.

FIG. 13.—*Lepidocyclina* (*Eulepidina*) *undosa* Cushman. Equatorial thin section of megalospheric specimen, ×17.8. From same locality as Figure 9.

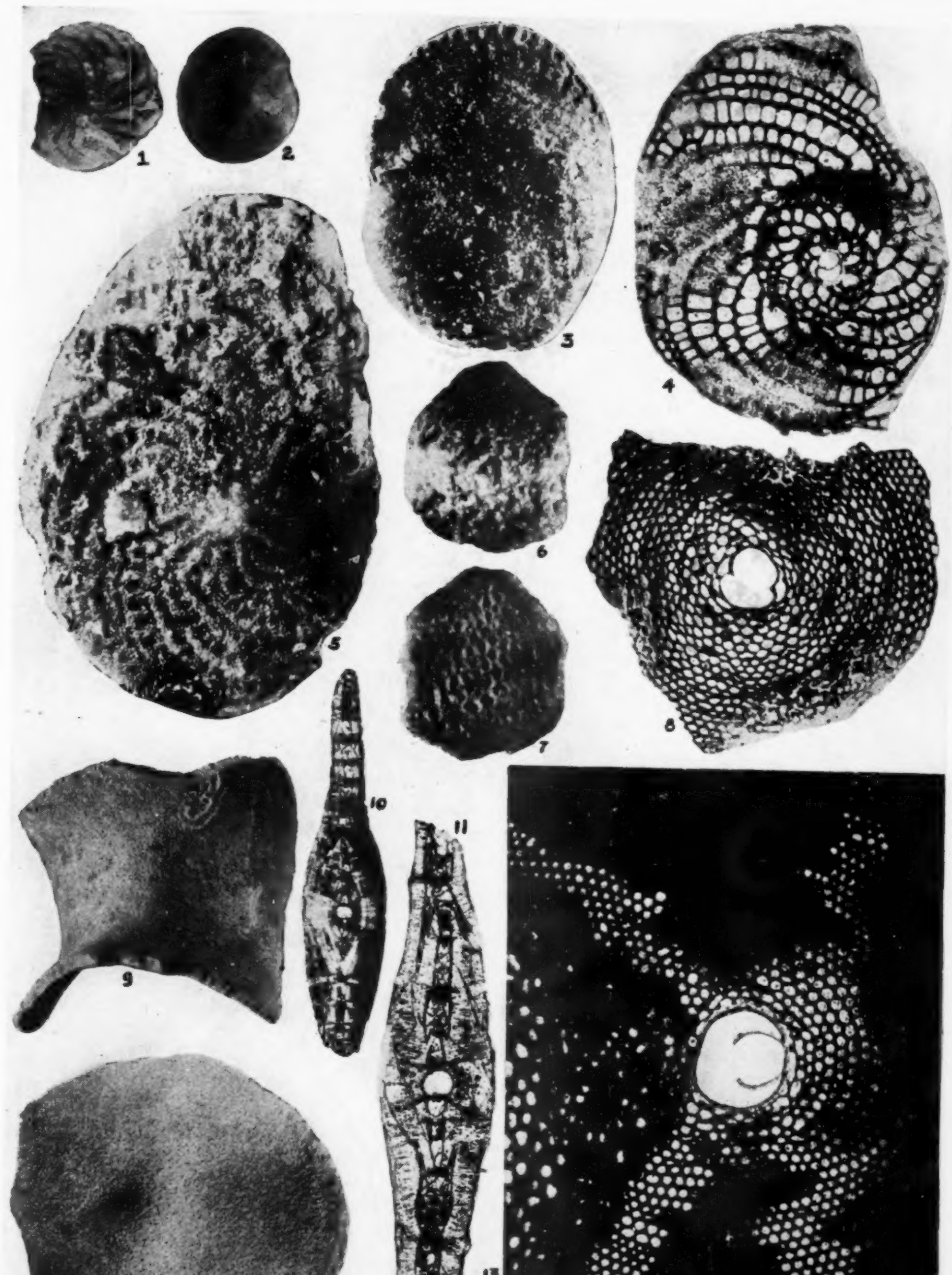


PLATE I

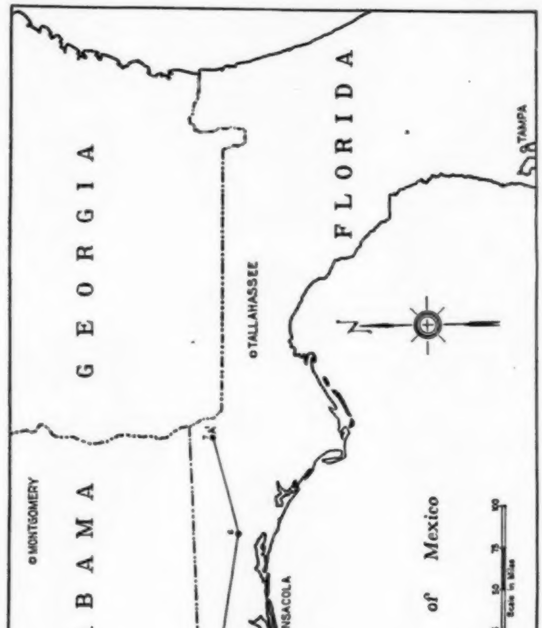


FIG. 2.—Index map showing location of sections *AA′*, *BB′*, and *CC′*.

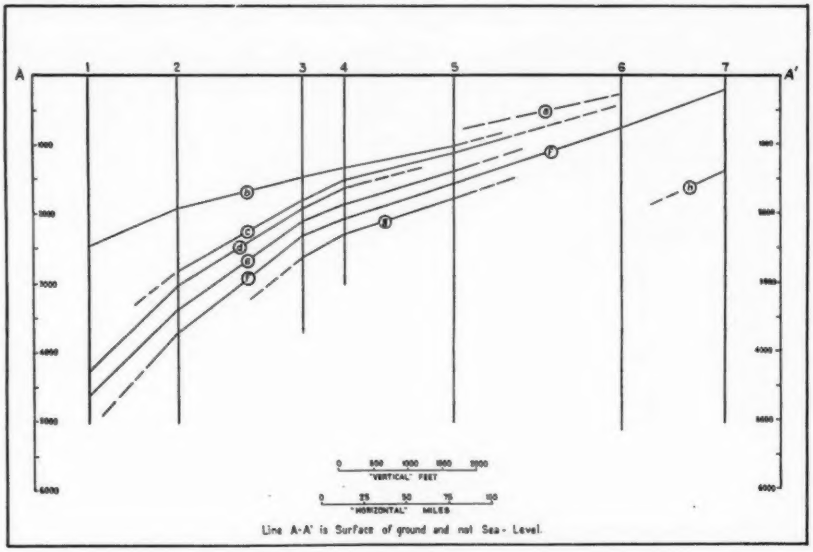


FIG. 3.—Section *AA'*, slightly oblique to general strike, showing distribution of some zones.

1. T. S. Stoneman's Ventrees No. 1, Sec. 38, T. 2 N., R. 3 W., Wilkinson County, Mississippi.
2. Pike County Oil Company's E. A. Causey No. 1, Sec. 28, T. 3 N., R. 7 E., Pike County, Mississippi.
3. Gulf Refining Company of Louisiana's Southern Lumber and Timber Company No. 2, Sec. 11, T. 1 N., R. 13 W., Forest County, Mississippi.
4. F. E. Curson's Newman Lumber Company No. 1, Sec. 26, T. 1 N., R. 9 W., Perry County, Mississippi.
5. McCurry and Danciger's Southern Kraft No. 1, Sec. 28, T. 2 S., R. 4 E., Baldwin County, Alabama.
6. Estabrook's Walton Land and Timber Company No. 1, Sec. 12, T. 1 N., R. 19 W., Walton County, Florida.
7. Scott Hammond's Branbery No. 1, Sec. 15, T. 5 N., R. 9 W., Jackson County, Florida.

a. *Mollusca* zone
b. *Miogypsina-Heterostegina* zone
c. *Lepidocyclina* (*Eulepidina*) zone
d. *Lepidocyclina mantelli* zone
e. *Camerina jacksonensis* zone
f. *Lepidocyclina* (*Polylepidina*) zone
g. *Discocyclina advena* zone
h. *Discocyclina blanpiedi-D. cookei* zone

cyclina) *colei* Gravell and Hanna,[8] and *Lepidocyclina* (*Lepidocyclina*) *texana* Gravell and Hanna[9] have been found in the downdip phases

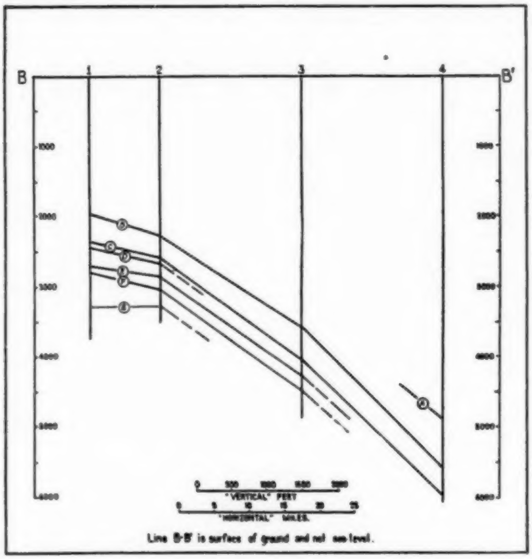


FIG. 4.—Section *BB'*, approximately a dip section, showing distribution of some zones.

1. Gulf Refining Company of Louisiana's Southern Lumber and Timber Company No. 1, Sec. 10, T. 1 S., R. 16 W., Pearl River County, Mississippi.
2. Gulf Refining Company of Louisiana's Goodyear Yellow Pine No. 2, Sec. 23, T. 2 S., R. 17 W., Pearl River County, Mississippi.
3. Gulf Refining Company of Louisiana's May Williams No. 1, Sec. 33, T. 5 S., R. 17 W., Pearl River County, Mississippi.
4. Danciger's Holdsworth No. 1, Sec. 26, T. 8 S., R. 14 E., St. Tammany Parish, Louisiana.

A. *Amphistegina* zone
B. *Miogypsina-Heterostegina* zone
C. *Lepidocyclina* (*Eulepidina*) zone
D. *Lepidocyclina mantelli* zone
E. *Camerina jacksonensis* zone
F. *Lepidocyclina* (*Polylepidina*) zone
G. *Discocyclina advena* zone

in Texas and Louisiana. The recording of them in Mississippi, Alabama, and Florida would not be unexpected.

Between the marine *Miogypsina-Heterostegina* zone and the top

[8] *Ibid*., pp. 526–27, Pl. 61, Fig. 1; Pl. 63, Fig. 5; Pl. 64. Figs. 1–6.

[9] *Ibid*., pp. 527–28, Pl. 65, Figs. 1–7.

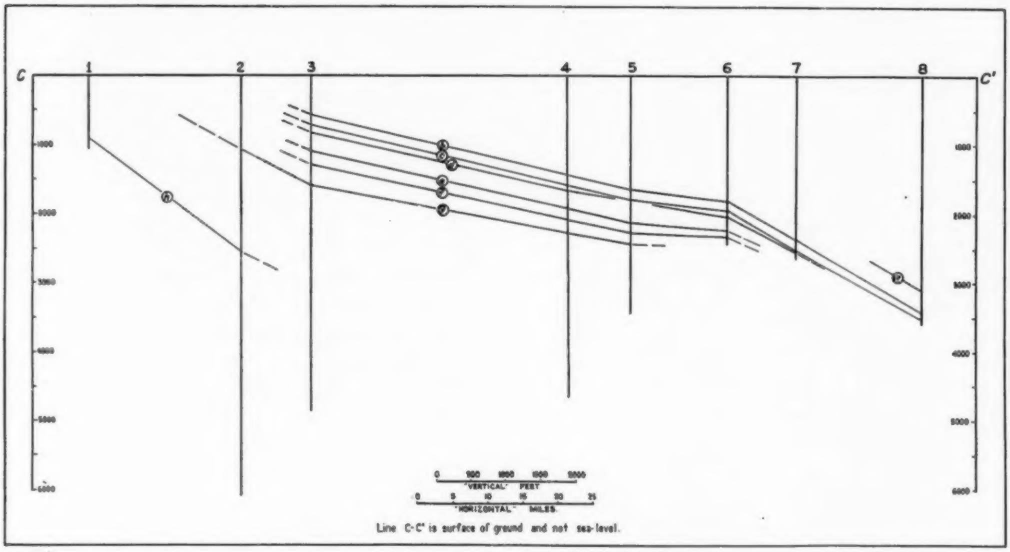


FIG. 5.—Section CC', approximately a dip section, showing distribution of some zones.

1. Gulf Refining Company of Louisiana's Thornton No. 1, Sec. 21, T. 9 N., R. 2 W., Choctaw County, Alabama.
2. Arkansas Fuel Oil Company's McClure No. 1, Sec. 4, T. 5 N., R. 2 W., Washington County, Alabama.
3. Danciger's Avant No. 1, Sec. 25, T. 5 N, R. 4 W., Washington County, Alabama.
4. Cleve Love's Newman No. 1, Sec. 9, T. 1 S., R. 8 W., George County, Mississippi.
5. Gulf Refining Company of Louisiana's Dantzler Lumber Company No. 8, Sec. 10, T. 2 S., R. 9 W., George County, Mississippi.
6. Gulf Refining Company of Louisiana's Pascagoula Lumber Company No. 2, Sec. 15, T. 3 S., R. 7 W., George County, Mississippi.
7. Gulf Refining Company of Louisiana's Dantzler Lumber Company No. 1, Sec. 27, T. 4 S., R. 8 W., Jackson County, Mississippi.
8. Gulf Refining Company of Louisiana's Dantzler Lumber Company No. 5, Sec. 32, T. 7 S., R. 6 W., Jackson County, Mississippi.

a. *Amphistegina* zone
b. *Miogypsina-Heterostegina* zone
c. *Lepidocyclina* (*Eulepidina*) zone
d. *Lepidocyclina mantelli* zone
e. *Camerina jacksonensis* zone
f. *Lepidocyclina* (*Polylepidina*) zone
g. *Discocyclina advena* zone
h. *Discocyclina blanpiedi-D. cookei* zone

of the *Lepidocyclina* (*Eulepidina*) zone is a series of non-marine sands and shales which vary in thickness from probably less than 100 feet in Alabama and eastern Mississippi to more than 700 feet in western Mississippi. This thickening is apparent in section *AA′* (Fig. 3).

LEPIDOCYCLINA (*EULEPIDINA*) ZONE

The *Lepidocyclina* (*Eulepidina*) zone is a well marked and easily recognizable zone, present in outcrop localities from Florida across Alabama and into eastern Mississippi where it is well developed in the vicinity of Waynesboro, Wayne County. This zone is well developed in the subsurface, being present from the outcrop at least as far downdip as the Gulf of Mexico (sections *BB′* and *CC′*) (Fig. 4 and Fig. 5) and along the strike from Florida across southern Alabama as far west as Pike County, Mississippi, where it is present in the Pike County Oil Company's Causey No. 1 (section *AA′*) (Fig. 3).

To date *Lepidocyclina* (*Eulepidina*) has been found only rarely in Louisiana and has not been recognized in Texas. The scarcity of *Lepidocyclina* (*Eulepidina*) in Louisiana and Texas is probably because different ecologic conditions prevailed in these areas. It appears from the known distribution of *Lepidocyclina* (*Eulepidina*) *favosa* Cushman[10] and *Lepidocyclina* (*Eulepidina*) *undosa* Cushman[11] (Pl. 1, Figs. 9, 13; Pl. 2, Fig. 5), eastern Gulf Coast, Antigua, Venezuela, Mexico, *et cetera*, that they required warm water and possibly also water fairly free from terrigenous material.

L. (*Eulepidina*) *favosa* and *L.* (*Eulepidina*) *undosa* have been con-

[10] Joseph A. Cushman, *Carnegie Inst. Washington Pub. 291* (1919), p. 66, Pl. 3, Figs. 1, 2, b; Pl. 15, Fig. 4.

[11] *Ibid.*, p. 65, Pl. 2, Figs. 1, a.

EXPLANATION OF PLATE 2

FIG. 1.—*Lepidocyclina* (*Lepidocyclina*) *mantelli* (Morton). Surface view of microspheric specimen, ×4.31. From fork of main road and side road on south line of Sec. 13, T. 9 N., R. 7 W., Wayne County, Mississippi, 100 yards east of secondary road bridge over Horton Mill Creek.

FIG. 2.—*Lepidocyclina* (*Lepidocyclina*) *mantelli* (Morton). Surface view of megalospheric specimen, ×4.31. From same locality as Figure 1.

FIG. 3.—*Lepidocyclina* (*Lepidocyclina*) *supera* (Conrad). Vertical thin section of megalospheric specimen, ×17.8. From under wagon bridge over Pearl River, Byram, Mississippi.

FIG. 4.—*Lepidocyclina* (*Lepidocyclina*) *supera* (Conrad). Vertical thin section of microspheric specimen, ×17.8. From same locality as Figure 3.

FIG. 5.—*Lepidocyclina* (*Eulepidina*) *undosa* Cushman. Vertical thin section of megalospheric specimen, ×17.8. From 55 feet above Limestone Creek at side of Highway 45, about ¼ mile east of bridge over Limestone Creek on this highway. Sec. 25, T. 9 N., R. 7 W., Wayne County, Mississippi.

FIG. 6.—*Lepidocyclina* (*Lepidocyclina*) *mantelli* (Morton). Vertical thin section of microspheric specimen, ×17.8. From St. Stephens Bluff, Washington County, Alabama.

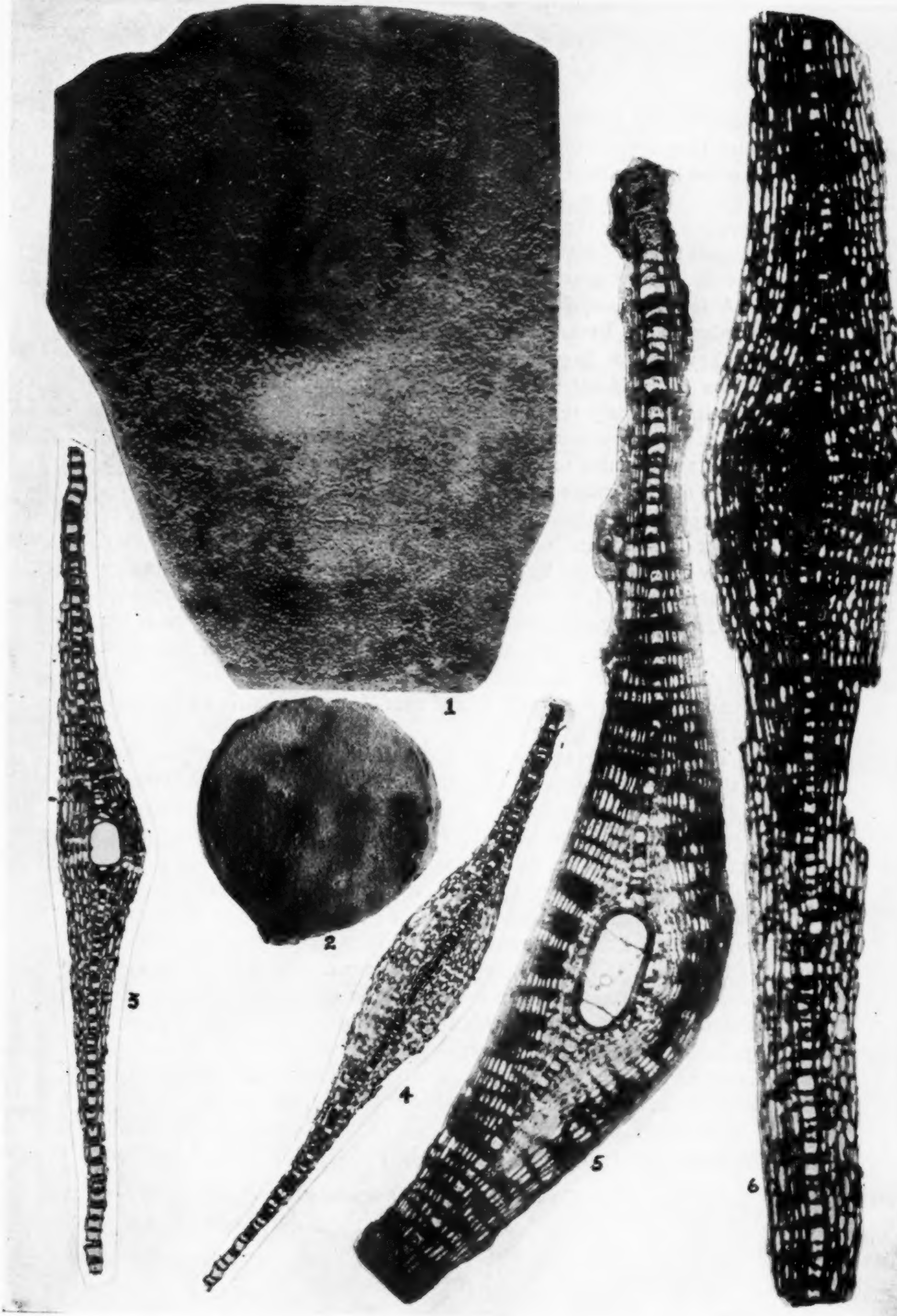


PLATE 2

sidered by the writers as worthy of designation as zone markers because they are abundant and fairly large (up to ½ inch or more in diameter). They have a very characteristic set of initial chambers (Pl. 1, Fig. 13) which makes identification fairly easy. Also their stratigraphic range in the Gulf Coast is somewhat restricted. They are abundant in the Chickasawhay, but, excepting a few which have been reworked into younger sediments, they have not been found above it.

A few *Lepidocyclina* (*Eulepidina*) have been found in outcrop samples of the Byram at Byram, Mississippi, and in the Glendon, but they are rare. In general appearance they closely resemble *Lepidocyclina* (*Eulepidina*) *undosa*. Further work may show that they are varieties of closely related but different species.

The *Lepidocyclina* (*Eulepidina*) zone is fairly thin, from a few feet in a few places to possibly 50 feet or more in others. It consists largely of light-colored marls, soft chalks with some hard limestones. Although the induration of the harder zones makes identification of smaller foraminifera difficult, the *Lepidocyclina* (*Eulepidina*) may readily be determined by sectioning the material. Study of the smaller foraminifera by H. V. Howe[12] has shown that their ranges for the most part are long. Approximately 41 per cent of the smaller species are found in the Vicksburg and 50 per cent in the Chipola. It is apparent that the relatively short-ranged *Lepidocyclina* (*Eulepidina*) with its abundance, good preservation, and ease of recognition, is a good horizon marker.

The interval from the top of the *Miogypsina-Heterostegina* zone to the top of the *Lepidocyclina* (*Eulepidina*) zone in western Alabama and eastern Mississippi is relatively small and uniform, approximately 125–200 feet (section *CC'*, Fig. 5) which is approximately a dip section). The wells on this section from the Danciger's Avant No. 1 in Washington County, Alabama, to the Gulf Refining Company's Dantzler No. 5 in Jackson County, Mississippi, contain both zones and the section shows the somewhat uniform thickness of the interval.

Section *AA'* (Fig. 3), which is approximately a strike section, shows the interval between the top of the *Miogypsina-Heterostegina* zone and the top of the *Lepidocyclina* (*Eulepidina*) zone to thicken gradually between the McCurry's Southern Craft No. 1 in Baldwin County, Alabama, where it has an interval of approximately 125 feet, and Curson's Newman No. 1 in Perry County, Mississippi, where it has an interval of approximately 200 feet. Westward from Curson's Newman No. 1 toward the Mississippi River this interval increases

[12] Henry V. Howe, *Shreveport Geol. Soc. Itinerary Report for Eleventh Annual Field Trip* (1934), p. 23.

within a short distance to nearly 1,000 feet in the Pike County Oil Company's Causey No. 1 in Pike County, Mississippi. The western dip section *BB'* (Fig. 4) also shows the thickness of the interval between the tops of these zones; the wells on this section show a somewhat uniform interval of approximately 400 feet.

LEPIDOCYCLINA (LEPIDOCYCLINA) SUPERA ZONE AND *LEPIDOCYCLINA (LEPIDOCYCLINA) MANTELLI* ZONE

These two zones are discussed together as they are zone markers within the Vicksburg. The first of the two represents the younger zone and the second the older. In the area considered in this paper both are found in many surface outcrops, and material is easily accessible for study. The Vicksburg as a group consists of limestones, chalks, and marls which are in part glauconitic. In certain areas some shales and sands are present but these are of minor importance. The thickness varies from place to place. It is apparently absent in some places due to erosion before the succeeding beds were deposited (Gulf Refining Company's Dantzler No. 8, section *CC'* (Fig. 5)). In general the thickness is less than 100 feet. As already stated the exact thickness can not be determined in many wells since only cuttings are available for study.

Lepidocyclina (*Lepidocyclina*) *supera* (Conrad)[13] (Pl. 1, Figs. 8, 12; Pl. 2, Figs. 3–4) and *Lepidocyclina* (*Lepidocyclina*) *mantelli* (Morton)[14] (Pl. 2, Figs. 1–2, 6; Pl. 3, Fig. 2) have been designated as zone fossils because of their size, preservation in the more indurated and cemented rocks, and their restriction to fairly limited vertical ranges. Geographically they are widely distributed where the Vicksburg is calcareous, which includes most of Mississippi, Alabama, and Florida where the Vicksburg is present. Westward in Louisiana and Texas the lithologic character of the Vicksburg changes to shales with minor amounts of sand. *Lepidocyclina* have been found recently in this section in Texas and it is believed that when these are critically studied some light will be thrown on the precise correlation between the Vicksburg of Texas and that of Mississippi.

DISCOCYCLINA (ASTEROCYCLINA) ZONE

In Florida, parts of Alabama, and Mississippi several species of *Discocyclina* (*Asterocyclina*) are found in the Ocala limestone. Asso-

[13] T. A. Conrad, *Proc. Acad. Nat. Sci. Philadelphia*, No. 2 (1865), p. 74. Described as *Orbitolites supera.*

[14] S. G. Morton, *Amer. Jour. Sci.*, Vol. 23 (1833), p. 291, Pl. 5, Fig. 9. Described as *Nummulites mantelli.*

ciated with them are several other species of larger foraminifera some of which are *Lepidocyclina* (*Lepidocyclina*) *ocalana* Cushman,[15] *Operculinoides wilcoxi* (Heilprin)[16] (Pl. 3, Figs. 1, 3, and 6), *Operculinoides ocalana* (Cushman),[17] and *Heterostegina ocalana* Cushman[18] (Pl. 3, Fig. 4). The writers have figured *Discocyclina* (*Asterocyclina*) *georgiana* (Cushman)[19] (Pl. 3, Fig. 5) and *Discocyclina* (*Asterocyclina*) *mariannensis* (Cushman)[20] (Pl. 4, Fig. 1). Vaughan[21] gave a good list of the Ocala larger foraminifera.

Although many other species are present this zone is referred to as the *Discocyclina* (*Asterocyclina*) zone because the subgenus *Asterocyclina* is easily identified and has a relatively short stratigraphic range, apparently being restricted to the Upper Eocene, occurring in many parts of the world where warm marine waters existed during the Upper Eocene, namely southern Europe, Venezuela, Trinidad, Jamaica, Panama, the East Indies, as well as in the eastern Gulf Coast region of the United States where the subgenus is apparently restricted to the upper part of the Jackson. To date the writers have not observed it in the Moody's Branch.

[15] Joseph A. Cushman, *U. S. Geol. Survey Prof. Paper 125* (1920), pp. 71–72, Pl. 28, Figs. 3–4; Pl. 29, Figs. 1–3.

[16] A. Heilprin, *Proc. Acad. Nat. Sci. Philadelphia* (1882), p. 191, text Figs. 1–2. Described as *Nummulites wilcoxi*.

[17] Joseph A. Cushman, *U. S. Geol. Survey Prof. Paper 128* (1921), p. 129, Figs. 4–5. Described as *Operculina ocalana*.

[18] *Ibid.*, pp. 130–31, Pl. 21, Figs. 15–18.

[19] Joseph A. Cushman, *U. S. Geol. Survey Prof. Paper 108* (1918), p. 117, Pl. 41, Figs. 2–3; Pl. 42, Fig. 3; Pl. 43, Figs. 2–3. Described as *Orthophragmina georgiana*.

[20] *Ibid.*, pp. 116–17, Pl. 40, Fig. 5; Pl. 42, Fig. 2; Pl. 44. Described as *Orthophragmina mariannensis*.

[21] Thomas Wayland Vaughan, *Florida Geol. Survey 19th Ann. Rept.* (1928), pp. 155–65, Pl. 1, Figs. 1–7; Pl. 2, Figs. 1–9.

EXPLANATION OF PLATE 3

FIG. 1.—*Operculinoides wilcoxi* (Heilprin). Surface view, ×17.8. From shallow road cut on north side of Highway 19, 3½ miles west of the junction of Highway 19 with Highway 5 in the town of Williston, Florida, immediately in front of the residence of W. M. Adams on his 119-acre farm.

FIG. 2.—*Lepidocyclina* (*Lepidocyclina*) *mantelli* (Morton). Equatorial thin section of megalospheric specimen, ×17.8. From St. Stephens Bluff, Washington County, Alabama.

FIG. 3.—*Operculinoides wilcoxi* (Heilprin). Half section of specimen cut through median plane, ×17.8. From same locality as Figure 1.

FIG. 4.—*Heterostegina ocalana* Cushman. Surface view, ×17.8. From quarry of Aixi Lime Products Company, on Highway 41, 6½ miles north of Ocala, Florida.

FIG. 5.—*Discocyclina* (*Asterocyclina*) *georgiana* (Cushman). Surface view, ×17.8. From bottom of core from 3,050–64 feet in the Gulf Refining Company of Louisiana's Southern Land and Royalty Company No. 1, Sec. 18, T. 5 S., R. 13 W., Harrison County, Mississippi.

FIG. 6.—*Operculinoides wilcoxi* (Heilprin). Vertical thin section, ×17.8. From same locality as Figure 1.

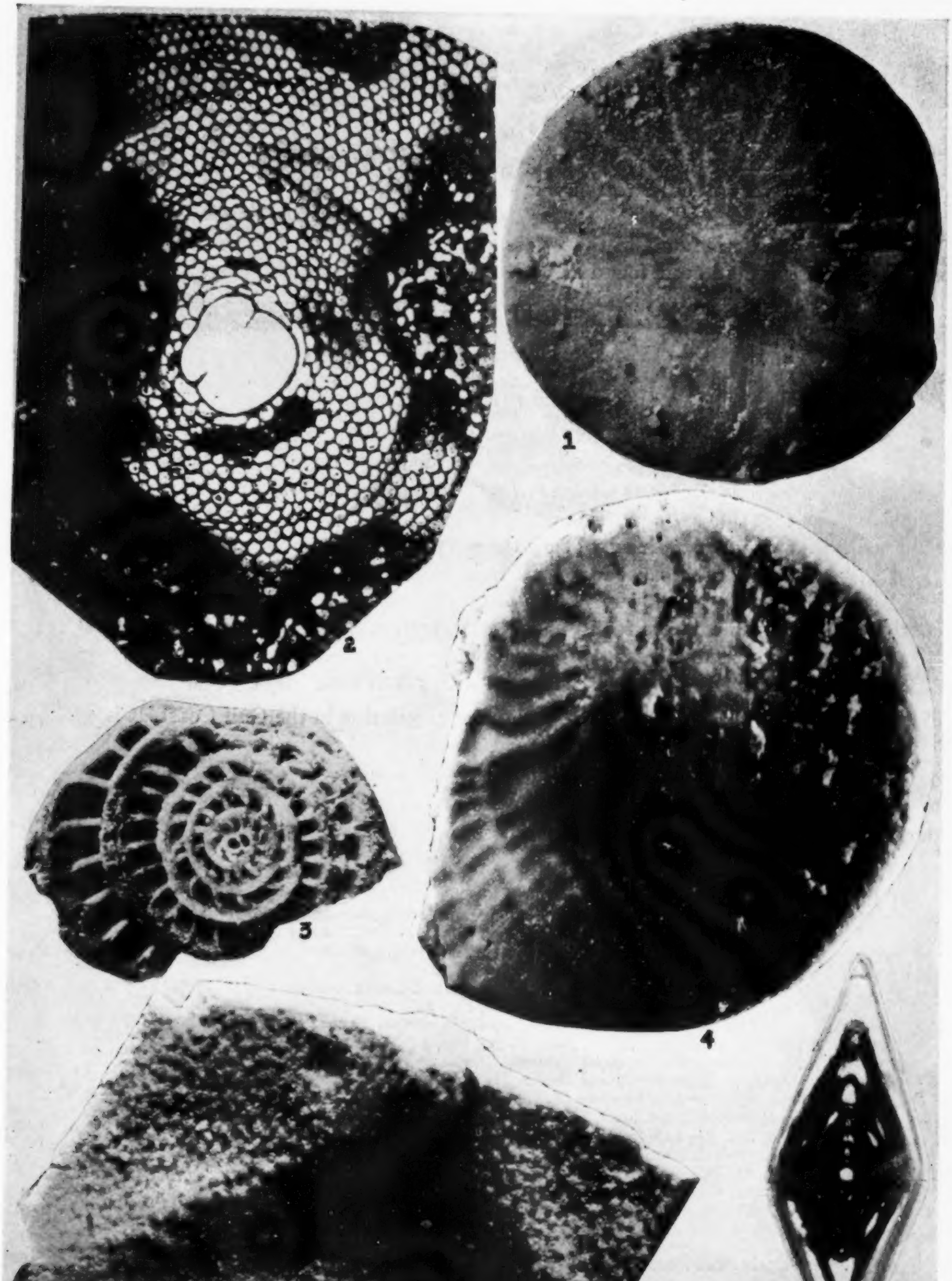


PLATE 3

Because the subgenus *Asterocyclina* can be readily recognized from cuttings and its upper range is restricted to the top of the Ocala, it is a very useful stratigraphic marker, especially where the Jackson is represented by the Ocala limestone facies. To date the larger foraminiferal fauna of the *Discocyclina* (*Asterocyclina*) zone of the Ocala has not been found beyond the limestone phases of the Jackson. Their geographic distribution apparently was limited to water conditions which favored lime formation. The genus *Discocyclina* is not known above the top of the Eocene.

OPERCULINA MARIANNENSIS ZONE

The *Operculina mariannensis* zone possibly should have been included under the *Discocyclina* (*Asterocyclina*) zone, since it does occur with *Discocyclina* (*Asterocyclina*) *mariannensis*. However, because the first *Operculina mariannensis* Vaughan[22] (Pl. 4, Fig. 10) found in well samples is ordinarily below the top of the *Discocyclina* (*Asterocyclina*) zone, and because it appears to have a somewhat different geographic distribution, it is given the rank of a separate zone. It is ordinarily common where found and is a distinctive species, which makes it a good zone marker.

CAMERINA JACKSONENSIS ZONE

This zone is one of the best for correlation in the Gulf Coast. It is one of the few zones which maintain somewhat similar lithologic and

[22] *Ibid.*, p. 158, Pl. 1, Figs. 1–4.

EXPLANATION OF PLATE 4

FIG. 1.—*Discocyclina* (*Asterocyclina*) *mariannensis* (Cushman). Surface view, ×17.8. From quarry of the Florida Basic Rock Company, 10 miles northwest of Mariana, Florida, on local road 3 miles east of Highway 6.

FIG. 2.—*Operculina vaughani* Cushman. Vertical thin section, ×17.8. After Gravell and Hanna. Donald W. Gravell and Marcus A. Hanna, "Larger Foraminifera from the Moody's Branch Marl, Jackson Eocene, of Texas, Louisiana, and Mississippi," *Jour. Paleon.*, Vol. 9, No. 4 (1935), Pl. 29, Fig. 16.

FIG. 3.—*Camerina jacksonensis* Gravell and Hanna. Surface view, ×17.8. Syntype after Gravell and Hanna. *Ibid.*, Pl. 29, Fig. 7.

FIG. 4.—*Lepidocyclina* (*Lepidocyclina*) *mortoni* Cushman. Surface view, ×17.8. After Gravell and Hanna. *Ibid.*, Pl. 30, Fig. 4.

FIG. 5.—*Camerina jacksonensis* Gravell and Hanna. Vertical half section, ×17.8. Syntype after Gravell and Hanna. *Ibid.*, Pl. 29, Fig. 11.

FIG. 6.—*Lepidocyclina* (*Lepidocyclina*) *mortoni* Cushman. Vertical thin section of megalospheric specimen, ×17.8. After Gravell and Hanna. *Ibid.*, Pl. 32, Fig. 3.

FIG. 7.—*Lepidocyclina* (*Lepidocyclina*) *mortoni* Cushman. Vertical thin section of microspheric specimen, ×17.8. After Gravell and Hanna. *Ibid.*, Pl. 32, Fig. 2.

FIG. 8.—*Operculina vaughani* Cushman. Surface view, ×17.8. After Gravell and Hanna. *Ibid.*, Pl. 29, Fig. 21.

FIG. 9.—*Camerina jacksonensis* Gravell and Hanna. Half section cut through median plane, ×17.8. Syntype after Gravell and Hanna. *Ibid.*, Pl. 29, Fig. 4.

FIG. 10.—*Operculina mariannensis* Vaughan. Surface view, ×17.8. From same locality as Figure 1.

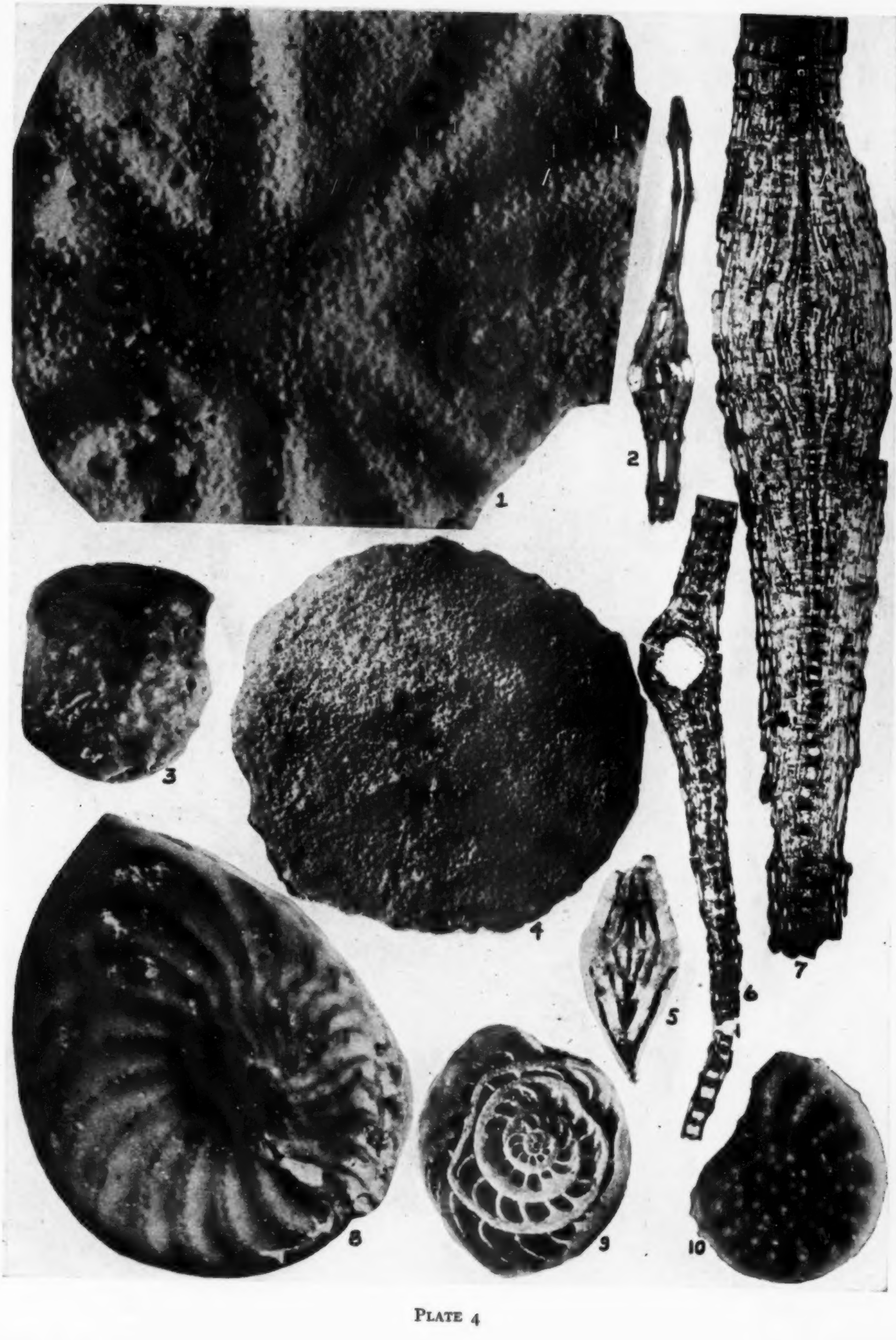


PLATE 4

ecologic characteristics both east and west of the Mississippi River. Its maximum thickness as far as has been observed by the writers is less than 100 feet and is commonly less than 50 feet. In Texas and Louisiana this zone can be fairly definitely recognized by its lithologic characteristics alone, but east of the Mississippi River, particularly where the Jackson assumes Ocala characteristics, such recognition is less reliable and in many places not possible.

The zone is composed chiefly of glauconitic quartz sands, glauconitic sandy marls, and green sand marls which ordinarily contain many fragments of fossils. It is more or less coextensive with the Moody's Branch marl but extends as a zone beyond the limits of the typical Moody's Branch marl and into its sandy limestone equivalent of the Ocala.

Although several larger foraminifera are present in this zone and characterize it equally well, *Camerina jacksonensis* Gravell and Hanna[23] (Pl. 4, Figs. 3, 5, 9) has been designated as the zone fossil

[23] Donald W. Gravell and Marcus A. Hanna, *Jour. Paleon.*, Vol. 9, No. 4 (1935), p. 331, Pl. 29, Figs. 1–5, 7–8, 10–11, 13–14.

EXPLANATION OF PLATE 5

FIG. 1.—*Camerina moodybranchensis* Gravell and Hanna. Surface view, ×17.8. Syntype after Gravell and Hanna. Donald W. Gravell and Marcus A. Hanna, "Larger Foraminifera from the Moody's Branch Marl, Jackson Eocene, of Texas, Louisiana, and Mississippi," *Jour. Paleon.*, Vol. 9, No. 4 (1935), Pl. 29, Fig. 22.

FIG. 2.—*Camerina moodybranchensis* Gravell and Hanna. Vertical half section, ×17.8. Syntype after Gravell and Hanna. *Ibid.*, Pl. 29, Fig. 15.

FIG. 3.—*Lepidocyclina* (*Lepidocyclina*) *mortoni* Cushman. Equatorial thin section of megalospheric specimen, ×17.8. After Gravell and Hanna. *Ibid.*, Pl. 31, Fig. 2.

FIG. 4.—*Camerina moodybranchensis* Gravell and Hanna. Half section ground through median plane, ×17.8. Syntype after Gravell and Hanna. *Ibid.*, Pl. 29, Fig. 24.

FIG. 5.—*Nonionella cockfieldensis* Cushman and Ellisor. Side view, approximately ×80. Type after Cushman and Ellisor. Joseph A. Cushman and Alva C. Ellisor, "Two New Texas Foraminifera," *Contrib. Cushman Lab. Foram. Research*, Vol. 9, Pt. 4 (1933), Pl. 10, Fig. 11a.

FIG. 6.—*Nonionella cockfieldensis* Cushman and Ellisor. Side view, approximately ×80. Type after Cushman and Ellisor. *Ibid.*, Pl. 10, Fig. 11b.

FIG. 7.—*Nonionella cockfieldensis* Cushman and Ellisor. Edge view, approximately ×80. Type after Cushman and Ellisor. *Ibid.*, Pl. 10, Fig. 11c.

FIG. 8.—*Eponides yeguaensis* Weinzierl and Applin. Dorsal view, approximately ×100. Cotype after Weinzierl and Applin. Laura Lane Weinzierl and Esther R. Applin, "The Claiborne Formation on the Coastal Domes," *Jour. Paleon.*, Vol. 3, No. 4 (1929), Pl. 42, Fig. 2a.

FIG. 9.—*Eponides yeguaensis* Weinzierl and Applin. Ventral view, approximately ×100. Cotype after Weinzierl and Applin. *Ibid.*, Pl. 42, Fig. 2b.

FIG. 10.—*Eponides yeguaensis* Weinzierl and Applin. Edge view, approximately ×100. Cotype after Weinzierl and Applin. *Ibid.*, Pl. 42, Fig. 2c.

FIG. 11.—*Camerina* sp. Surface view of accidental half-section, ×17.8. From top of core from 2,291–98 feet in the Gulf Refining Company of Louisiana's Pascagoula Lumber Company No. 2, Sec. 15, T. 3 S., R. 7 W., George County, Mississippi.

FIG. 12.—*Ceratobulimina eximia* (Rzehak) var. Ventral view, approximately ×100. After Weinzierl and Applin. *Ibid.*, Pl. 42, Fig. 3b.

FIG. 13.—*Camerina* sp. Half section of specimen shown in Figure 11, broken through median plane, ×17.8.

FIG. 14.—*Ceratobulimina eximia* (Rzehak) var. Dorsal view, approximately ×100. After Weinzierl and Applin. *Ibid.*, Pl. 42, Fig. 3a.

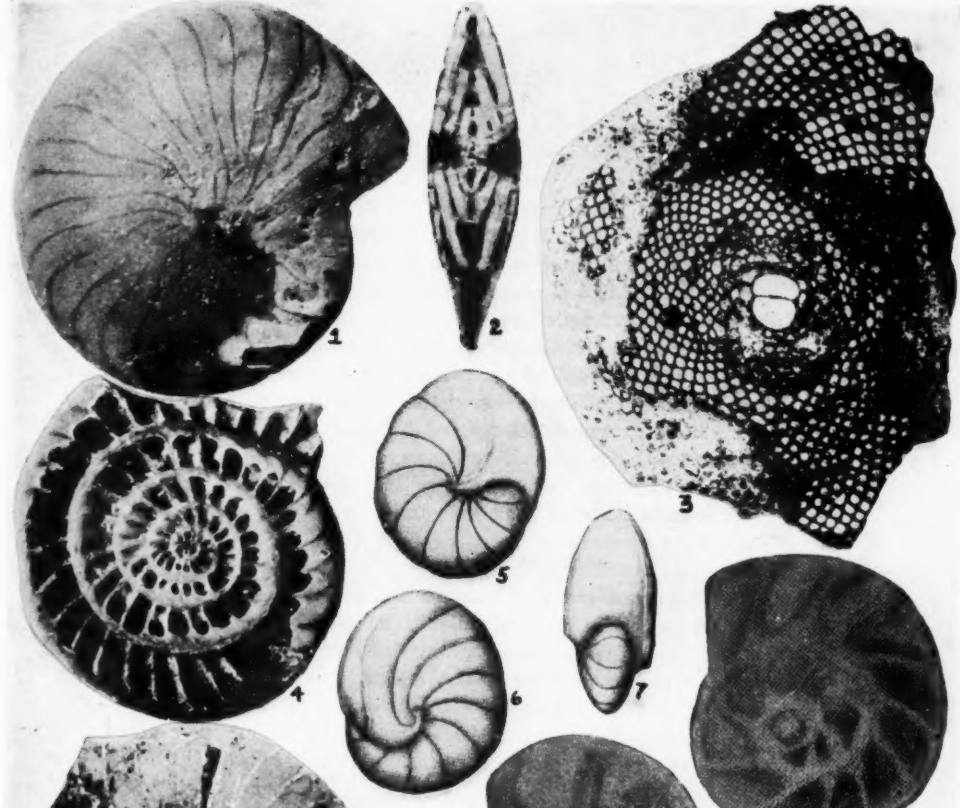


PLATE 5

as it is very easily recognized, is very common throughout the area under discussion, and is generally well preserved and seldom broken. *Camerina moodybranchensis* Gravell and Hanna[24] (Pl. 5, Figs. 1, 2, 4) is equally characteristic but is less common east of the Mississippi River than west of the Mississippi. *Operculina vaughani* Cushman[25] (Pl. 4, Figs. 2, 8) is common but is ordinarily broken, particularly in cuttings. *Discocyclina flintensis* (Cushman)[26] is characteristic and widespread but is fragile and in places badly broken. *Lepidocyclina* (*Lepidocyclina*) *mortoni* Cushman[27] (Pl. 4, Figs. 4, 6–7; Pl. 5, Fig. 3) is widespread and an excellent index fossil for the zone, but as with certain of the *Lepidocyclina* it is commonly broken in cuttings. Any of these species are characteristic of the *Camerina jacksonensis* zone and can be used with equal certainty. However, as *Camerina jacksonensis* is probably the more common, more widely distributed, and more easily identified the zone has been named for it.

NONIONELLA COCKFIELDENSIS ZONE

Nonionella cockfieldensis Cushman and Ellisor[28] (Pl. 5, Figs. 5–7) is used extensively in Texas and Louisiana as a zone marker. It may have greater geographic distribution through Mississippi and Alabama than the records show. The interval between the *Camerina jacksonensis* zone above and the *Camerina* (large) and the *Lepidocyclina* (*Polylepidina*) zone below is small. The writers have noted *Nonionella cockfieldensis* in wells in western Mississippi but have not observed it eastward.

EPONIDES YEGUAENSIS ZONE

Eponides yeguaensis Weinzierl and Applin[29] (Pl. 5, Figs. 8–10) is used in Texas and Louisiana extensively as a zone maker. The writers have noted it in many wells in western Mississippi but it is less commonly noted eastward, in a large part due to change in the thickness and lithologic character of the section. The interval between the *Camerina jacksonensis* zone above and the *Camerina* (large) zone

[24] *Ibid.*, pp. 332–33, Pl. 29, Figs. 15, 22–24.

[25] Joseph A. Cushman, *U. S. Geol. Survey Prof. Paper 128* (1921), p. 128, Pl. 19, Figs. 6–7.

[26] Joseph A. Cushman, *U. S. Geol. Survey Prof. Paper 108* (1918), pp. 115–16, Pl. 40, Figs. 1–2. Described as *Orthophragmina flintensis*.

[27] Joseph A. Cushman, *U. S. Geol. Survey Prof. Paper 125* (1920), pp. 70–71, Pl. 27, Figs. 1–4, Pl. 28, Figs. 1–2.

[28] Joseph A. Cushman and Alva C. Ellisor, *Contrib. Cushman Lab. Foram. Research*, Vol. 9, Pt. 4 (1933), pp. 95–96, Pl. 10, Figs. 11 a–c.

[29] Laura Lane Weinzierl and Esther R. Applin, *Jour. Paleon.*, Vol. 3, No. 4 (1929), pp. 406–07, Pl. 42, Figs. 2 a–c. Described as *Eponides guayabalensis* Cole var. *yeguaensis*.

below or the *Lepidocyclina* (*Polylepidina*) zone below is small, making its use unnecessary.

CERATOBULIMINA EXIMIA ZONE

Ceratobulimina eximia (Rzehak)[30] (Pl. 5, Figs. 12, 14) is used extensively in Texas and Louisiana in placing the top of the Cook Mountain. In western Mississippi *Ceratobulimina eximia* is commonly recorded at the same position in the section as in Texas and Louisiana. Eastward, however, due at least in part to ecologic changes, it is commonly rare or absent at the top of the Cook Mountain. A prolonged search might reveal it in the shaly parts of the section but in the limestone part it appears to be absent. It has a much longer vertical range than *Camerina* (large) or *Lepidocyclina* (*Polylepidina*) *gardnerae*. *Ceratobulimina eximia* ranges from the top of the Cook Mountain to at least the base of the Weches. It is commonly noted in wells but ordinarily not until the *Camerina* (large) zone and the *Lepidocyclina* (*Polylepidina*) zone have been penetrated. Its scarcity has led the writers to consider *Ceratobulimina eximia* less reliable east of the Mississippi River than west of it.

CAMERINA (LARGE) ZONE

This zone has been found to be of value in this part of the Claiborne section. At least two species of *Camerina* (Pl. 5, Figs. 11 and 13; Pl. 6, Figs. 2 and 5; Pl. 7, Figs. 5 and 6) are present, a smooth one and a beaded one. As far as the writers have been able to determine neither species has been described and rather than introduce a nude name they are referred to merely as large. They appear to be scarce or absent in western Mississippi. Eastward as the section becomes more marly or calcareous *Operculinoides* (large) appear in abundance. In the harder limestones the surface may not break free from the matrix but some specimens break along the median plane and recognition is easy. In cuttings they can ordinarily be found by screening the coarser material from the finer. The interval from the top of the *Camerina jacksonensis* zone to the first appearance of *Camerina* (large) is commonly between 50 and 80 feet. This zone is not shown on the section since it is such a short distance below the *Camerina jacksonensis* zone.

LEPIDOCYCLINA (*POLYLEPIDINA*) ZONE

This zone is one of the most useful in the correlation of the Gulf Coast Claiborne since geographically it is found from eastern Texas

[30] A. Rzehak, *Ann. k.k. Nat. Hofmuseum* (1888), Vol. 3, Pt. 3, p. 263, Pl. 11, Figs. a–c. Described as *Pulvinulina eximia*.

to Florida. For the present *Lepidocyclina* (*Polylepidina*) is referred to *Lepidocyclina* (*Polylepidina*) *gardnerae* Cole[31] (Pl. 6, Figs. 1, 3–4, 6–7, and 9), although it is recognized that more than one species may be present. It is for this reason that the zone has been designated the *Lepidocyclina* (*Polylepidina*) zone, and no species cited. It is the first appearance of the subgenus in well samples that the writers have found valuable for marking the top of the zone. The subgenus *Polylepidina* is easily recognized by the character of the embryonic apparatus.

The *Lepidocyclina* (*Polylepidina*) zone is somewhat thicker than some of the other zones discussed in this paper. It has been found in a few wells through a section of as much as 200 feet. The interval between the top of the *Camerina* (large) zone and the top of the *Lepidocyclina* (*Polylepidina*) zone is approximately 30-70 feet.

In many places associated with *Lipidocyclina* (*Lepidocyclina*) *gardnerae* are *Discocyclina perpusilla* Vaughan[32] and several species of *Camerina* and *Operculinoides*.

DISCOCYCLINA ADVENA ZONE

The *Discocyclina advena* zone is an extremely useful zone for stratigraphic correlation as it is quite thin, probably not more than

[31] W. Storrs Cole, *Bull. Amer. Paleon.*, Vol. 15, No. 56 (1929), pp. 60–62, Pl. 1, Figs. 1–6; Pl. 2, Figs. 1–2.

[32] Thomas Wayland Vaughan, *Proc. U. S. Nat. Museum*, Vol. 76, Art. 3 (1929), pp. 9–11, Pl. 2, Figs. 3–5, 5a.

EXPLANATION OF PLATE 6

FIG. 1.—*Lepidocyclina* (*Lepidocyclina*) *gardnerae* Cole. Equatorial thin section of megalospheric specimen, ×17.8. From core from 2,360–64 feet in the Gulf Refining Company of Louisiana's Pascagoula Lumber Company No. 2, Sec. 15, T. 3 S., R. 7 W., George County, Mississippi.

FIG. 2.—*Camerina* sp. Surface of accidental half-section of microspheric specimen, ×17.8. From top of core from 2,291–98 feet in same well as Figure 1.

FIG. 3.—*Lepidocyclina* (*Polylepidina*) *gardnerae* Cole. Surface view, ×6. From cuttings from 51–63 feet in the Snowden's Henderson No. 2, Wm. H. Holman Survey, Angelina County, Texas.

FIG. 4.—*Lepidocyclina* (*Polylepidina*) *gardnerae* Cole. Vertical thin section of megalospheric specimen, ×52.5. From core from 2,356–60 feet in the same well as Figure 1.

FIG. 5.—*Operculinoides* sp. Accidental half-section of microspheric specimen shown in Figure 2, ×17.8.

FIG. 6.—*Lepidocyclina* (*Polylepidina*) *gardnerae* Cole. Vertical thin section of megalospheric specimen, ×14. From same locality as Figure 3.

FIG. 7.—*Lepidocyclina* (*Polylepidina*) *gardnerae* Cole. Equatorial thin section of megalospheric specimen, ×15. From same locality as Figure 3.

FIG. 8.—*Discocyclina advena* (Cushman). Surface view, ×8.5. From cuttings from 2,760–77 feet in the Deering's Freund No. 1, Patrick B. O'Conner Survey, Grimes County, Texas.

FIG. 9.—*Lepidocyclina* (*Polylepidina*) *gardnerae* Cole. Vertical thin section of microspheric specimen, ×17.8. From core from 2,356–60 feet in same well as Figure 1.

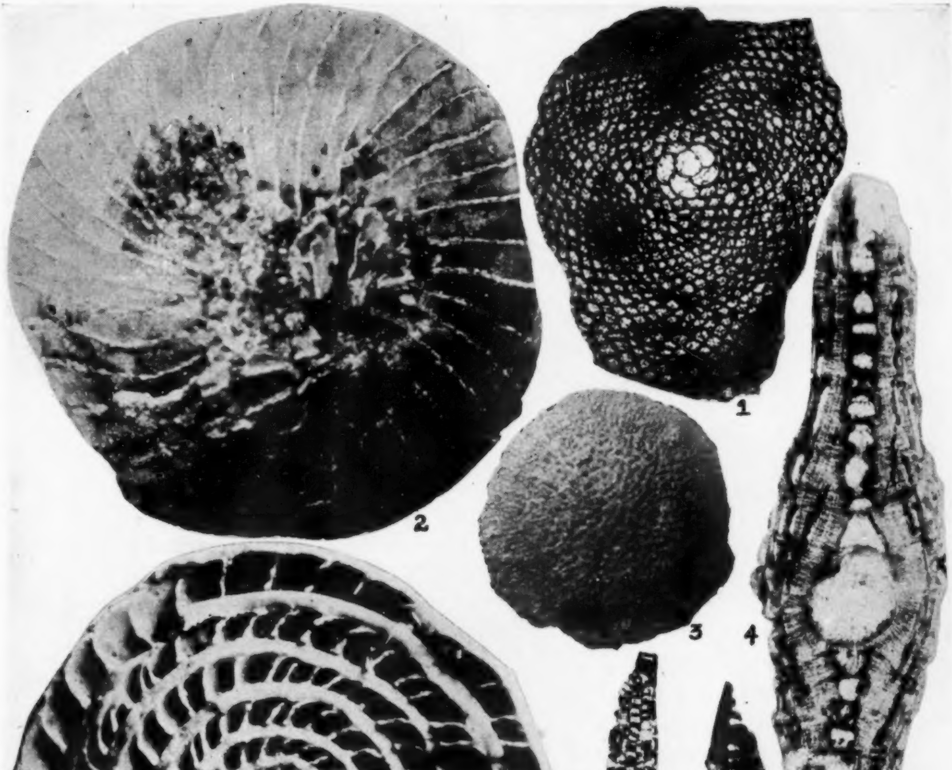


PLATE 6

50 feet in thickness, and as it has very wide geographical distribution. It occurs geographically from McCurry's Southern Kraft No. 1, Baldwin County, Alabama, just a few miles from the western line of Florida, through Mississippi, Louisiana, and as far west as Colorado County, Texas. It has also been found in numerous outcrop samples. It was described from the Cane River at Victoria Mills, Natchitoches Parish, Louisiana.

Discocyclina advena (Cushman)[33] (Pl. 6, Fig. 8; Pl. 7, Figs. 4–5) is found in a zone which grades from a glauconitic marl in its western portion to a hard glauconitic to slightly glauconitic limestone in its eastern portion. In addition to its short stratigraphic range and its wide geographic distribution *Discocyclina advena* is a very useful zone marker as it differs distinctly from all other species of this genus which are found in this area in its delicate anastomosing surface ornamentation (fairly smooth, without distinct papillae, fairly large size, and with a depressed central area rather than attaining its greatest thickness through the center). This species is readily recognized even in cuttings and its first or highest appearance furnishes a very useful and accurate zone for correlation.

DISCOCYCLINA BLANPIEDI-DISCOCYCLINA COOKEI ZONE

The writers are not as well acquainted with this zone as with those discussed in the foregoing because the zone has not been penetrated in many of the wells examined. Both *Discocyclina blanpiedi* Vaughan[34] (Pl. 7, Figs. 1–3) and *Discocyclina cookei* Vaughan[35]

[33] Joseph A. Cushman, *U. S. Geol. Survey Prof. Paper 128* (1921), pp. 139–42, Pl. 22, Figs. 1–5. Described as *Orthophragmina advena.*

[34] Thomas Wayland Vaughan, *Jour. Paleon.*, Vol. 10, No. 4 (1936), pp. 254–56, Pl. 41, Figs. 1–7.

[35] *Ibid.*, pp. 256–58, Pl. 42, Figs. 1–6.

EXPLANATION OF PLATE 7

FIG. 1.—*Discocyclina blanpiedi* Vaughan. Surface view, ×15. At underground spring, Sec. 34, T. 6 N., R 2 E., Clark County, Alabama.

FIG. 2.—*Discocyclina blanpiedi* Vaughan. Equatorial thin section, ×43. From same locality as Figure 1.

FIG. 3.—*Discocyclina blanpiedi* Vaughan. Vertical thin section, ×43. From same locality as Figure 1.

FIG. 4.—*Discocyclina advena* (Cushman). Equatorial thin section, ×15. From cuttings from 2,760–77 feet in the Deering's Freund No. 1, Patrick B. O'Conner Survey, Grimes County, Texas.

FIG. 5.—*Camerina* sp. Vertical half-section of megalospheric form, ×17.8. From top of core from 2,291–98 feet in the Gulf Refining Company of Louisiana's Pascagoula Lumber Company No. 2, Sec. 15, T. 3 S., R. 7 W., George County, Mississippi.

FIG. 6.—*Camerina* sp. Vertical half-section of microspheric form, ×17.8. From same locality as Figure 5.

FIG. 7.—*Discocyclina cookei* Vaughan. Equatorial thin section, ×43. From road cut at foot of Salt Mountain limestone hill, southwest corner Sec. 34, T. 6 N., R. 2 E., Clark County, Albama.

FIG. 8.—*Discocyclina advena* (Cushman). Vertical thin section, ×15. From same locality as Figure 4.

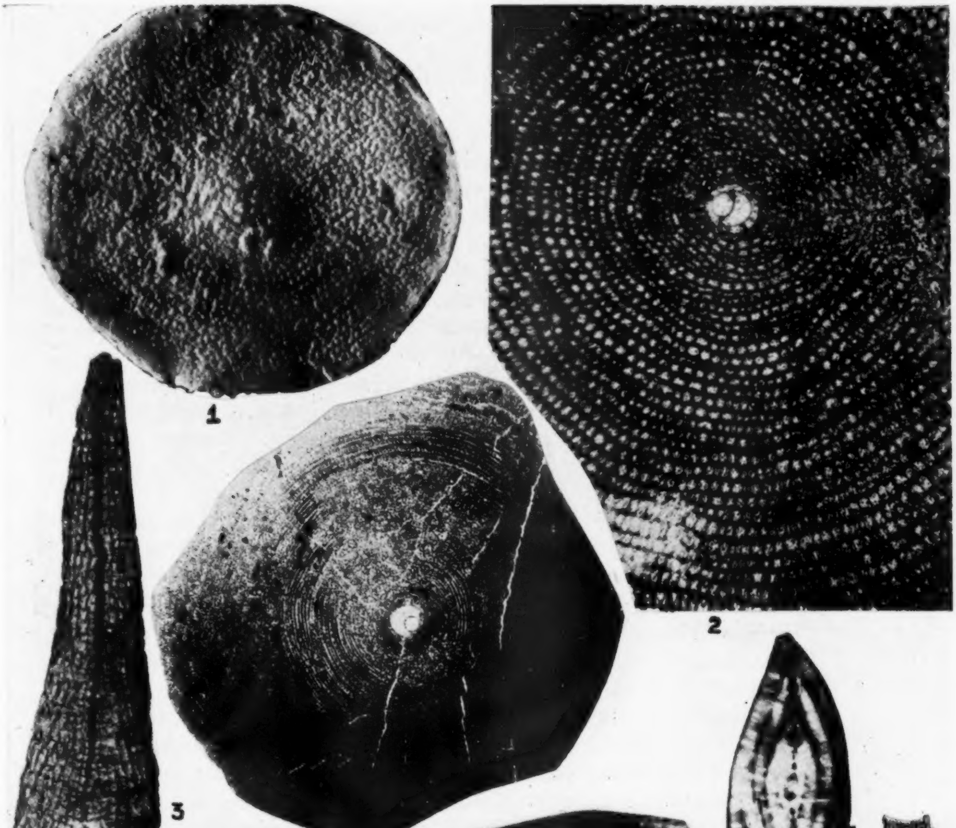


PLATE 7

(Pl. 7, Fig. 6) appear to be restricted to the Salt Mountain limestone and to a relatively thin zone. They are fairly common in the marl and limestone facies. The extent of their geographic distribution is not known. They have been found in surface samples and wells in Alabama. The interval between the top of the *Discocyclina advena* zone and the top of the *Discocyclina blanpiedi-D. cookei* zone has been determined in only a few wells. In the Arkansas Fuel Company's McClure No. 1, Washington County, Alabama, the interval is approximately 1,450 feet.

Since this paper was presented *Discocyclina cookei* has been found in the Gulf Oil Corporation's Adolphus Ragan No. 2, Segno field, Polk County, Texas, in a core from 8,722–27 feet.

SECTIONS

It is to be noted that certain variations appear in the intervals in the three sections. These variations may be due to actual thickening and thinning of the sections, to gaps in suites of samples, or to the nature of the samples—whether they are cores or cuttings. Each of many of the cores and cuttings represents as much as 30 feet or more of section. The points used in the cross sections are the highest points represented by the samples containing particular zone fossils. For example, if zone fossil *A* is found in a cutting from 3,000–30 feet, a point of 3,000 feet is used on the cross section. Actually zone fossil *A* may have been at 3,029 feet rather than 3,000 feet, but this can not be determined from the cutting. Speed of drilling may cause considerable lag since the cuttings must come to the surface of the ground before being secured. This discrepancy is greater with more rapid progress in drilling. When a well caves the material being drilled may not appear in sufficient amount for recognition until the bit has penetrated some depth below the top of a zone. These considerations are not confined to this area but apply equally well to other areas when correlations are made on cuttings alone.

Some of the zones listed on the correlation chart are not shown on the sections because of the small interval between them and other zones, which would crowd the lines on the section too close together, making them appear almost as single heavy lines. The zones not shown are *Lepidocyclina supera* zone, *Discocyclina* (*Asterocyclina*) zone, *Operculina mariannensis* zone, and the *Camerina* (large) zone.

SECTION AA' (FIG. 3)

Section *AA'* is an oblique strike section. It extends from near the Mississippi River at the Stoneman's Ventrees No. 1, Wilkinson

County, Mississippi, across southern Mississippi and Alabama into north-central Florida, a distance of a little more than 300 miles. Seven wells are given on this section to show the relative position and distribution and intervals of the zones. The most extensive zone throughout the section is the *Lepidocyclina* (*Polylepidina*) zone, which is found in all but the westernmost well of the section. It is also probably present there but samples were not from sufficient depth to reach the zone. *Discocyclina blanpiedi-D. cookei* zone was observed in but one well, Scott Hammond's Granbery No. 1, Jackson County, Florida.

SECTION BB′ (FIG. 4)

Section *BB′* is nearly a dip section extending in a straight line a distance between 40 and 50 miles. Four wells are given to show in a general way the dip through the area and the intervals between the zones. *Lepidocyclina* (*Lepidocyclina*) *mantelli* zone was not noted in the Gulf Refining Company's May Williams No. 1. The *Discocyclina* (*Asterocyclina*) zone was noted in the Gulf Refining Company's Southern Lumber No. 1, Gulf Refining Company's Goodyear No. 2, and the Gulf Refining Company's May Williams No. 1 but are not indicated on the section.

SECTION CC′ (FIG. 5)

Section *CC′* is nearly a dip section and extends a straight-line distance of approximately 90 miles. Eight wells are given to show in a general way the dip through the area and the intervals between the zones. No zones were selected in the Gulf Refining Company's Thornton No. 1 above the *Discocyclina blanpiedi-D. cookei* zone because the well is too far updip. In the Arkansas Fuel's McClure No. 1 a gap in samples existed between 242–45 feet and 965–85 feet. *Lepidocyclina* (*Polylepidina*) *gardnerae* was present in the latter sample but because of the lack of samples the top of the *Lepidocyclina* (*Polylepidina*) zone could not be determined. This was true also of the zones above the *Lepidocyclina* (*Polylepidina*) zone. *Discocyclina blanpiedi-D. cookei* zone was not observed in the Danciger's Avant No. 1 or the Love's Newman No. 1. *Lepidocyclina* (*Lepidocyclina*) *mantelli* zone was not noted in the Gulf Refining Company's Dantzler No. 8. The *Discocyclina* (*Asterocyclina*) zone was present in the Gulf Refining Company's Dantzler No. 8, the Gulf Refining Company's Dantzler No. 1, and the Gulf Refining Company's Pascagoula No. 2 but was not indicated on the section. The *Camerina* (large) zone was present in the Danciger's Avant No. 1, Love's Newman No. 1, Gulf Refining Company's Dantzler No. 8, and the Gulf Refining Company's Pascagoula No. 2.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 1014-1019

COMPARISON OF PERMIAN AMMONOID ZONES OF SOVIET RUSSIA WITH THOSE OF NORTH AMERICA[1]

A. K. MILLER[2]
Iowa City, Iowa

ABSTRACT

In this paper an attempt is made to summarize briefly the available data in regard to the Permian ammonoid zones represented in Soviet Russia, and to compare them with the familiar western Texas zones. It is pointed out that the Wolfcamp horizon (zone of *Properrinites*) is represented in the Urals and in Crimea; the Leonard horizon (zone of *Perrinites*) is represented in the Urals, the Pamirs, and Darwaz; and the Word horizon (zone of *Waagenoceras*) is represented in Crimea and the Pamirs. No ammonoids are known from the Capitan horizon (zone of *Timorites*) in the U.S.S.R.

During the last few years the Russian geologists have made extensive studies of the Permian rocks of their vast country, and this work has yielded a great deal of information in regard to the abundance, variety, and distribution of ammonoids there. The results of their studies were presented in a large part at the recent meetings of the Seventeenth International Geological Congress, and it is the writer's purpose in this paper to acquaint American geologists with the data that are now available and to point out general correlations with American strata that can now be made on the basis of ammonoids. Acknowledgment is due to the State University of Iowa and particularly to Frederick O. Thompson of Des Moines, Iowa, for financial assistance which made possible the writer's studies in the U.S.S.R.

In the first place, it may be well to explain that, as in America, there is no unanimity of opinion among the Russian geologists as to just what should be included in the Permian system. Nevertheless, progress was made with this troublesome question during a conference on the Permian rocks of the U.S.S.R., which was held in Leningrad in February, 1937, and during the International Geological Congress of July and August, 1937. From the reports of these two meetings, it appears that tentatively, at least, a six-fold subdivision of the Permian rocks of the classical Ural region can be recognized, and that, from bottom to top, these subdivisions should be called Sakmarian, Artinskian, Kungurian, Ufimian, Kazanian, and Tartarian. However, it should be stated clearly in this connection that some of the Russians think that the Ufimian is merely a continental facies of the upper

[1] Manuscript received, March 7, 1938.

[2] State University of Iowa.

Kungurian and the lower Kazanian and that therefore we should use only a five-fold subdivision. Some believe that the Sakmarian, which includes particularly the so-called "*Schwagerina*" beds, should be placed in the Upper Carboniferous, whereas others (for example, Nalivkin and Ružencev) are equally certain that it should be classed as Permian. Also, there is some question about the upper boundary of the Permian in the Ural region, and Mazarowicz would place the upper part of the so-called Tartarian in the Triassic.

Nalivkin[3] has recently called attention to the fact that for the territory of the U.S.S.R. the Permian period was a time of a "rapid and considerable regression of the sea." That is, during Sakmarian time there was a "maximum development of seas and a minimum transportation of terrigenous material." Then, in the succeeding intervals, the Artinskian and the Kungurian, "the marine regime remained the most stable in the central part of the Russian Platform," but particularly during Kungurian times a variety of rocks was developed, including some red-beds, gypsum, and salt. Following this, a large closed brackish-water basin with an impoverished fauna was developed during Ufimian and Kazanian times and desiccated during the Tartarian interval.

As a result of this paleogeography, ammonoids, which apparently were very sensitive to salinity and lived only in normal sea water, are confined in the Urals to the lower part of the Permian. That is, insofar as the writer has been able to ascertain, Permian cephalopods have not been found in the Ural region proper above the Artinskian, though slightly younger Permian ammonoid faunas have been collected in Crimea and in the Pamirs. Furthermore, later marine Permian beds are known in central Asiatic U.S.S.R., that is, in the Pamirs and in Darwaz. So far, no ammonoids have been found in these strata, but the fusulinids indicate that some of them are the approximate stratigraphic equivalents of the Capitan of Texas and the Amarassi of Timor and that others (in the Pamirs) are probably as young as the *Cyclolobus* beds of India and Madagascar.

In the southern Urals (Orenburg and southern Bashkirian regions), the late Paleozoic rocks contain a succession of ammonoid faunas that show a striking parallelism with those known from western Texas. That is, along the Ural and the Sakmara rivers Ružencev[4] has found in his uppermost Upper Carboniferous (Orenburgian) numerous

[3] D. V. Nalivkin, "Paleogeography of the Permian in the U.S.S.R.," XVII *Internatl. Geol. Congress Abstracts of Papers* (1937), pp. 81–82.

[4] V. E. Ružencev, "The Boundary between the Carboniferous and the Permian Based upon Materials from the Orenburg Region and the South Bashkirian A.S.S.R.," XVII *Internatl. Geol. Congress Abstracts of Papers* (1937), pp. 89–90.

ammonoids, and last summer he showed us well preserved representatives of the ammonoid genera *Prouddenites* and *Uddenites* from this region. As is now generally recognized,[5] in western Texas these two genera are characteristic of the two youngest ammonoid zones known in the Pennsylvanian (Gaptank formation). Furthermore, both of these zones can be recognized in north-central Texas, and the *Prouddenites* zone is represented also in Oklahoma and Missouri. Of special interest in this connection is the finding by Ružencev of a primitive representative of the ammonoid genus *Artinskia* in the Upper Carboniferous (Orenburgian) of the southern Urals. This genus, which apparently arose from *Uddenites* through *Propinacoceras*, has always been regarded as characteristic of the Permian, and Gerassimov's discovery of typical representatives of it in the Sakmarian or "*Schwagerina*" beds on Mount Tra-Tau in the southern Urals tended to convince many of the members of the Seventeenth International Geological Congress that these beds are truly Permian. Recently Gerassimov[6] has illustrated and described these specimens as well as other ammonoids, including a primitive species of *Medlicottia*, from the same horizon and locality.

TABLE I

GENERAL CORRELATION OF LATE PALEOZOIC AMMONOID-BEARING BEDS OF U.S.S.R. WITH THOSE OF WESTERN TEXAS

		Western Texas	*Southern Urals*	*Crimea*	*Pamirs*	*Darwaz*
Upper Permian	Zone of *Timorites*	Capitan				
Middle Permian	Zone of *Waagenoceras*	Word		Martian and Bournien	Koubergandy	
	Zone of *Perrinites*	Leonard	Artinskian	Hiatus?	Bouz-téré	Piandj
Lower Permian	Zone of *Properrinites*	Wolfcamp	Sakmarian	Soramnien		
Upper Carboniferous	Zone of *Uddenites* Zone of *Prouddenites*	Gaptank	Orenburgian			

[5] F. B. Plummer and Gayle Scott, "Upper Paleozoic Ammonites in Texas," *Texas Univ. Bull. 3701* (1937), pp. 14–27.

[6] N. P. Gerassimov, "Ural Division of the Permian System," *Kazan* (1937), pp. 1–68, Pls. 1, 2.

In both the Ural and the Texas regions, the ammonoid zone next above the zone of *Uddenites* contains a fauna that is composed largely of elements typical of the overlying zones. In America the most characteristic genus of this fauna is *Properrinites*, which is represented in the Wolfcamp formation of western Texas, the Admiral formation of north-central Texas, and the Neva limestone (Big Blue series) of Kansas. Although this genus has been found in the Soramnien beds of Crimea, no representatives of it are known from the Urals. Nevertheless, the occurrence of closely similar species of *Artinskia*, *Paragastrioceras*, *Prothalassoceras*, *Agathiceras*, *Marathonites*, and *Vidrioceras* in the Russian Sakmarian and in the Texas Wolfcamp-Admiral beds indicates a general equivalency of the two, and this is substantiated by the fact that both are found between the zone of *Uddenites* and beds that have long been recognized as approximate correlatives. It should perhaps be remarked in this connection that in America the Pennsylvanian-Permian boundary line is now generally drawn below the rocks which contain the *Properrinites* fauna and above those that contain the *Uddenites* fauna, and many of the Russian geologists also believe that the lower limit of the Permian should be drawn here, that is, between the Orenburgian and the Sakmarian of the southern Urals. As is well known, it is difficult to determine where this boundary should be drawn. With the ammonoids, just as with other fossils, in certain of the uppermost Paleozoic faunal zones assemblages occur that are clearly Permian and in other stratigraphically lower zones assemblages are found that are typically Pennsylvanian, or Upper Carboniferous; the intermediate zones, however, yield a mixture of these two assemblages, and many genera cross almost any boundary that may be drawn. In general, however, it seems to the writer that if the *Uddenites* fauna is regarded as the youngest of the Upper Carboniferous faunas and the *Properrinites* fauna as the beginning of the Permian faunas, it will not be far wrong. The writer believes that the ammonoids are compatible with such a concept, though he does not believe that they establish it (Ružencev believes they do establish it).

Since the publication of Böse's classical work on the Permian ammonoids of the Glass Mountains of western Texas in 1919, the genus *Perrinites* has been regarded as the most characteristic form of the zone next above that of *Properrinites*. That genus was originally based on specimens from the Leonard formation of western Texas, but typical representatives of it have since been found elsewhere in Texas, in New Mexico, in Mexico, and in Timor, but not in the Ural region. Nevertheless, it has long been recognized that the numerous

ammonoids of the Artinskian, made known particularly by the excellent work of Karpinsky[7] and Ružencev[8] are closely related to those of the Leonard and equivalent beds in America and are of approximately the same age. According to Toumansky,[9] to whom we owe our knowledge of the Permian ammonoids of Crimea and the Pamirs, there has not yet been recognized in Crimea the horizon "correspondant à la Leonard formation du Texas et aux dépôts Bouz-téré du Pamir aux complexes *Perrinites* et *Marathonites*." The few poorly preserved ammonoids which Toumansky and Borneman[10] recently described from the Piandj River region in southwestern Darwaz are, as these authors recognized, most probably Artinskian in age—only the genera *Propinacoceras*, *Artinskia*, *Prosicanites*, *Popanoceras*, and possibly *Agathiceras* are known to be represented there.

Recently some American geologists have shown a tendency to regard certain of the Texas strata that contain *Perrinites* as equivalent to (or even younger than) those that contain *Waagenoceras*. However, all of the evidence the writer can deduce from a study of the ammonoids alone points clearly to the conclusion that *Perrinites* became extinct before the appearance of *Waagenoceras*.

In the Ural region no ammonoids have been found in the strata above the Artinskian, but the Bournien and Martian beds of Crimea and the Koubergandy beds of the Pamirs have yielded ammonoid faunas that are almost certainly of the same age as the Sosio beds of Sicily, the Basleo beds of Timor, and the Word formation of Texas. In Texas, as well as in Mexico, Sicily, and Timor, the most characteristic genus of this zone is perhaps *Waagenoceras*, but no representatives of it have so far been found in the U.S.S.R. Still the occurrence in Crimea[11] of many species identical with, or very closely similar to, those known from Sicily indicates an equivalence with the *Waageno-*

[7] A. Karpinsky, "Über die Ammoneen der Artinsk-Stufe und einige mit denselben verwandte carbonische Formen," *Mém. l'Acad. Imp. des Sci. de St-Pétersbourg*, sér. 7e, tome 37, no. 2 (1889), pp. 1–104, Pls. 1–5.

[8] V. E. Ružencev, "Sur quelques Ammonoidea du Permien inférieur provenant de la région d'Aktioubinsk," *Bull. Soc. Nat. Moscou, sec. géol.*, tome 11 [2] (1933), pp. 164–180, pls. 4, 5; and "Paleontological Notes on Carboniferous and Permian Ammonoids," *Problems of Soviet Geol.*, Vol. 6, No. 12 (1936), pp. 1072–88.

[9] O. G. Toumansky, "La stratigraphie du système permien d'après les ammonées," XVII *Internatl. Geol. Congress Abstracts of Papers* (1937), pp. 93–94.

[10] O. G. Toumansky and B. A. Borneman, "On the Permian Ammonoids of Darvaz," *Bull. Soc. Nat. Moscou, sec. géol.*, tome 15 [2] (1937), pp. 104–18, pl. 1.

[11] O. G. Toumansky, "The Permo-Carboniferous Beds of the Crimea, Part 1, Cephalopoda, Ammonoidea," *Geol. Survey, Paleontology and Stratigraphy* (1931), pp. 1–117, Pls. 1–8.

ceras-bearing beds. Also, as recognized by Toumansky,[12] the numerous but poorly preserved ammonoids, which in 1935 she described from the region of the Kubergandy River in the Pamirs, show a close affinity with those known from the Sosio beds of Sicily and the Bournien beds of Crimea, rather than with those known from the closer ammonoid-bearing strata in the southern Urals and Darwaz.

The Permian beds exposed along the Marta River in Crimea, that is, the beds which Toumansky has designated "Martian," have yielded the youngest Paleozoic ammonoid fauna known so far from within the confines of Soviet Russia. However, farther south, in India and Madagascar, occurs the *Cyclolobus* fauna, which is probably younger than the youngest Paleozoic ammonoid fauna known from America, the fauna of the Capitan of Texas and equivalent beds in northern Mexico. That is, in the Mexican state of Coahuila the beds with *Waagenoceras* are overlain by beds which carry an abundant ammonoid fauna, characterized particularly by the genera *Timorites* and *Strigogoniatites*, both of which were originally described from the Permian of Timor. *Strigogoniatites* has been found also in the Capitan, but *Timorites* is known only from the Upper Permian of Coahuila and Timor (Amarassi beds). *Timorites*, which belongs in the family Cyclolobidae, is in certain respects intermediate between typical *Waagenoceras* and typical *Cyclolobus*, and therefore the beds which contain it are probably also intermediate in age between those which contain *Waagenoceras* and those which contain *Cyclolobus*. In North America only a single species of Permian ammonoids is known to occur above the zone of *Timorites*—it belongs in an unnamed genus related to *Paralecanites*.

[12] *Idem*, "Permian Ammonoids of the Kubergandy River and Their Stratigraphical Significance," *Acad. Sci. U.S.S.R. Bull. 31* (1935), pp. 43–130, Pls. 1–5.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 1020-1047, 2 FIGS.

PETROLEUM AND NATURAL GAS IN NON-MARINE SEDIMENTS OF POWDER WASH FIELD IN NORTHWEST COLORADO[1]

W. T. NIGHTINGALE[2]
Rock Springs, Wyoming

ABSTRACT

The occurrence of considerable volumes of petroleum (1,000 barrels per day) and natural gas (34,000,000 cubic feet per day) in non-marine sediments of the Powder Wash field in northwest Colorado has recently attracted much attention. The petroleum and natural gas production occurs in continental deposits of Lower Eocene age known as the Hiawatha member of the Wasatch formation. Production is believed to be indigenous to the non-marine Wasatch formation and not migratory from either underlying or overlying formations. Saline waters occur in association with the petroleum-producing zones. Accumulation apparently is controlled by an upfolded Tertiary dome structure but within the confines of the structure producing horizons are extremely irregular. This irregularity is largely due to the highly lenticular sand bodies which are characteristic of the continental Wasatch formation.

The Powder Wash field is discussed as an example of a field productive of both petroleum and natural gas from non-marine sediments. The stratigraphy of the region and general structural conditions are described in some detail to prove as untenable any assumption of vertical migratory movement of hydrocarbons from other formations and any assumption of long-distance lateral migration is shown to be equally unsupportable. Two hypotheses to account for the presence of hydrocarbons in the nonmarine sediments at Powder Wash are presented. The unusual hazards involved in developing such fields in the Wasatch continental formation are discussed.

INTRODUCTION

The completion of two flowing oil wells and two natural gas wells by the Mountain Fuel Supply Company in the non-marine, Lower Eocene, Hiawatha member of the Wasatch formation of the Powder Wash field, together with the previous development of some oil and large volumes of natural gas in the same formation in the Hiawatha gas field,[3] 16 miles west of Powder Wash, has directed geological attention to the possible further occurrence of these hydrocarbons in commercial amounts in the widespread continental deposits of the Rocky Mountain Province where Eocene sediments of non-marine origin occur in an area in excess of 50,000 square miles in the states of Wyoming, Colorado, and Utah.

[1] Read by title before the Association at New Orleans, March 18, 1938. Manuscript received, March 25, 1938.

[2] Chief geologist, Mountain Fuel Supply Company.

[3] W. T. Nightingale, "Geology of Vermilion Creek Gas Area in Southwest Wyoming and Northwest Colorado," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 8 (August, 1930), pp. 1013-40.

Idem, "Geology of Hiawatha Gas Fields, Southwest Wyoming and Northwest Colorado," *Geology of Natural Gas* (Amer. Assoc. Petrol. Geol., June, 1935), pp. 341-61.

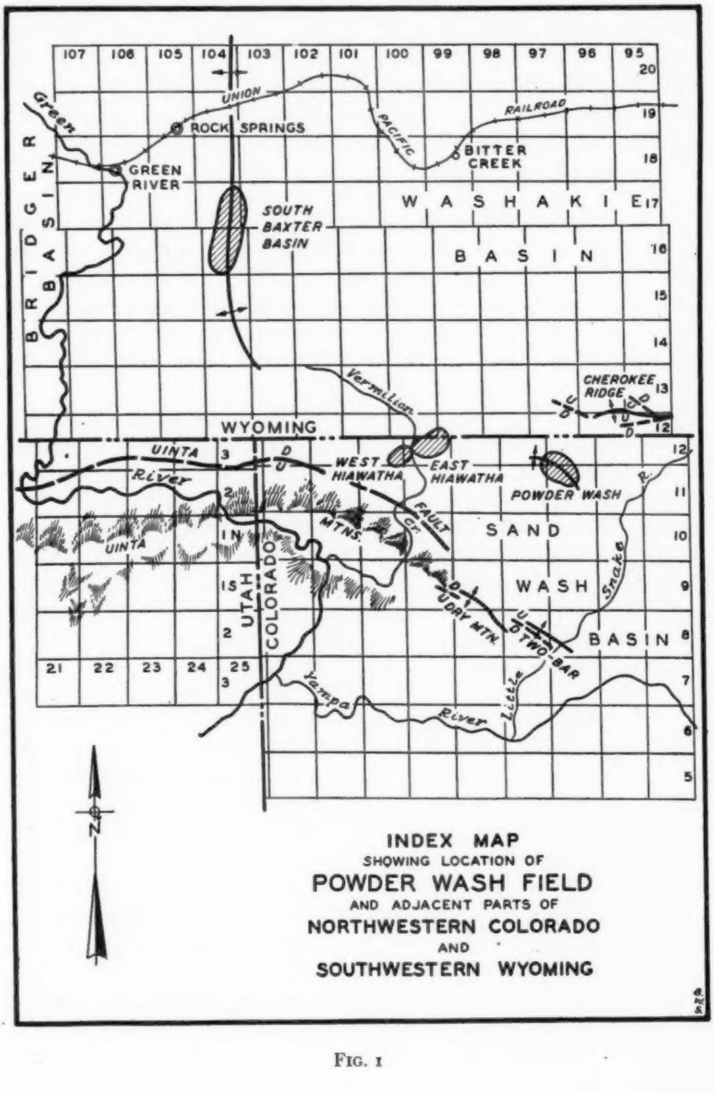

INDEX MAP
SHOWING LOCATION OF
POWDER WASH FIELD
AND ADJACENT PARTS OF
NORTHWESTERN COLORADO
AND
SOUTHWESTERN WYOMING
ROCK SPRINGS
GREEN RIVER
BITTER CREEK
UNION PACIFIC RAILROAD
WASHAKIE BASIN
BRIDGER BASIN
SOUTH BAXTER BASIN
CHEROKEE RIDGE
WYOMING
UTAH
COLORADO
WEST HIAWATHA
EAST HIAWATHA
POWDER WASH
SAND WASH BASIN
UINTA MTNS.
UINTA FAULT
DRY MTN.
TWO-BAR
Yampa River
Vermilion Cr.
Snake R.
Little Snake
Green

FIG. 1

ACKNOWLEDGMENTS

The writer is indebted to W. B. Emery, chief geologist, Western Division, The Ohio Oil Company, and to John G. Bartram, geologist, Stanolind Oil and Gas Company, for criticism of the manuscript, and to John McFadyen and J. C. Donnell II, vice-presidents of the Mountain Fuel Supply Company, for permission to publish this paper.

LOCATION

The Powder Wash oil and gas field is located within the drainage system of Little Snake River in Moffat County, northwest Colorado. Little Snake River is a tributary of Yampa River of northwest Colorado, which river in turn is tributary to Green River. Thus the Powder Wash area lies within the limits of the Green River drainage basin although it is southeast of the Green River structural basin of southwest Wyoming as that structural basin is usually delimited.

The Powder Wash field lies in Townships 11 and 12 North, Ranges 97 and 98 West of the Sixth Principal Meridian in Moffat County, northwest Colorado. The Colorado-Wyoming state line is less than three miles north of the present productive area of the field (Fig. 1).

By airline the Powder Wash field is 44 miles south, and slightly east, of Bitter Creek station on the main line of the Union Pacific Railroad. Rock Springs, Wyoming, is 92 miles, by road, northwest of Powder Wash field and Craig, Colorado, the county seat of Moffat County, is about 80 miles, by road, southeast of the field.

DEVELOPMENT

The original gas discovery well in the Powder Wash field was drilled in 1931 by Mountain Fuel Supply Company. This well, the B. W. Musser No. 1, was completed at 2,152 feet in the Hiawatha member of the non-marine Wasatch formation for an open flow volume of 34,000,000 cubic feet per day of natural gas at a pressure of 685 pounds per square inch. Inasmuch as the field had no pipe-line outlet, no further development was undertaken until the summer of 1936.

In July, 1936, the Carl Allen well No. 1 at Powder Wash was begun as a deep test by Mountain Fuel Supply Company. At 5,014 feet an oil-saturated sand was encountered in the Hiawatha member of the non-marine Wasatch formation which, when tested, produced at the rate of 1,100 barrels per day of 37.4° A. P. I. gravity oil with an estimated 3,000,000 cubic feet of gas. The well was completed in November, 1936.

Following the completion of the Carl Allen well No. 1, a location was made on the Hal W. Stewart acreage at Powder Wash field. This

well, the Hal W. Stewart No. 1, encountered an oil-saturated sand at 3,087 feet in the Hiawatha member of the non-marine Wasatch formation which, on testing, produced at the rate of 800 barrels per day. The oil in the Hal W. Stewart well is similar in character to that in the Carl Allen well although nearly 2,000 feet of stratigraphic interval separate the two producing horizons.

The J. C. Donnell well No. 1, the fourth well to be drilled at Powder Wash, was completed in August, 1937. This well was drilled to a total depth of 5,878 feet without encountering commercial oil production and then plugged back to 3,102 feet and completed as a 4,000,000 cubic foot natural gas well with a pressure of 1,030 pounds per square inch. The well also produces from a sand of non-marine origin in the Hiawatha member of the Wasatch formation.

Stratigraphy

General Statement

The sedimentary rocks exposed at Powder Wash and in the area adjacent thereto belong, for the greater part, to the upper Wasatch (Cathedral Bluffs tongue) and the overlying upper Green River formation (Laney shale member), both of Eocene age. A few remnants of the Brown's Park formation of probable Upper Miocene age, which once was widespread over the region and rested unconformably on all formations from the Bridger downward, is now represented in the Powder Wash area by only a few uneroded remnants and is not of importance in the discussion of petroleum and natural gas in the non-marine sediments of the region.

In northwest Moffat County, Colorado, 20 miles southwest of the Powder Wash area, rocks ranging in age from Upper Cretaceous to pre-Cambrian are exposed on the northeast flank of the Uinta Mountain uplift in the canyon of Vermilion Creek. In the Hiawatha gas field, 16 miles west of Powder Wash, a test well was drilled 7,577 feet in depth from the middle Wasatch formation of Eocene age to the middle Mesaverde formation of Upper Cretaceous age. The geological column in northwestern Moffat County, Colorado, which includes the Powder Wash area, is shown in Table I and is determined by using the Vermilion Creek stratigraphic information together with the Wasatch and lower formational thickness as determined by drilling at Powder Wash and Hiawatha and the outcropping post-Wasatch formations of the area.

In any comprehensive consideration of the occurrence of petroleum and natural gas in the non-marine sediments of the Wasatch formation it becomes necessary to describe in some detail those for-

TABLE I

SECTION OF GEOLOGICAL FORMATIONS AS EXPOSED OR DRILLED IN NORTHWEST MOFFAT COUNTY, COLORADO

SYSTEM	SERIES	GROUP AND FORMATION		THICKNESS (Feet)	CHARACTER AND REMARKS
TERTIARY	Miocene(?)	Brown's Park formation		0-1200	White to brown cross-bedded, wind-blown sandstone. Much tuffaceous material. Weathers readily.
		Unconformity			
	Eocene	Bridger formation		800 ±	Gray ashy clay shales, soft sandstone. Occasional reddish and green color bands. Fluviatile and lacustrine in origin.
		Green River formation	Laney shale member (upper Green River formation)	1200 ±	Blue-gray to buff, thinly laminated shales together with low grade oil shales. Massive sandstones near top and some sands near base. Lacustrine in origin.
			Cathedral Bluffs tongue (upper Wasatch formation)	1750-1850	Cathedral Bluffs tongue largely reddish clay shale with brown coarse grained sandstones. Continental origin.
		Wasatch formation	Tipton shale tongue (lower Green River formation)	75 ±	Hard, thin bedded, fissle shale weathering to distinctive light bluish-gray color on outcrop. Largely oil shale. Lacustrine origin.
			Hiawatha member (lower Wasatch formation)	3535-4054	Hiawatha member includes gray to variegated clay shale, gray to buff lenticular sandstones, some red shale and several coal horizons. Continental origin. Oil and gas production PowderWash.
		Unconformity			
TERTIARY(?)	Eocene(?)	Post-"Laramie" formation		336	Dark gray to drab shales with numerous fine coal and carbonaceous streaks. Gray to brown sandstones. Small pebble conglomerate, usually at base.
CRETACEOUS	Upper Creta-ceous	Laramie formation		1754	Gray to brown sandstones, dark shales, thin coal beds.
		Montana Group	Lewis shale	526	Gray to drab marine shales.
			Mesa-verde Sub-Group: Williams Fork formation	1600 ±	Gray to brown medium-grained sandstones interbedded with gray shales and coal.
			Mesa-verde Sub-Group: Iles formation	1700 ±	Massive, light gray sandstones with minor amounts of interbedded gray sandy shale. Marine fossils.
			Steele shale	3092	Dark gray marine clay shale, thin sands in basal part, sandy lenses upper half. Montana fossils.
		Colorado Group	Niobrara shale	1683	Light gray to dark marine clay shale, thin sandstones, calcareous septarian concretions. Niobrara fossils.
			Carlile shale	316	Dark gray marine shale with brown sandstone concretions near top. Carlile fossils.
			Frontier formation	140	Massive, fine to medium-grained sandstones interbedded with dark carbonceous shale and some thin coal.
			Aspen shale	155	Hard, platy marine shale, weathers silvery gray; abundant fish scales.
		Dakota sandstone		160	Gray to brown, medium to coarse-grained sandstone with thin conglomerate at top and heavier conglomerate at base. Interbedded gray to greenish shale.

Note: Formations below Dakota sandstone down to pre-Cambrian Quartzite exposed in Vermilion Creek, Moffat County, northwest Colorado, and along Uinta Mountains. W.T.N.

The Tipton shale tongue (lower Green River formation) separates two Wasatch members by interfingering.

mations both underlying and overlying the Wasatch formation which, because of their hydrocarbon content in the general region, might perhaps be supposed to have been the original source of the oil and gas now found in the Powder Wash field. Thus Table I, which shows more than 11,000 feet of stratigraphic section below the Wasatch formation and above the base of the Upper Cretaceous, includes the Dakota sandstone and the Frontier formation, which yield petroleum or natural gas in some producing fields in northwest Colorado and southwest Wyoming. Table I also shows the position of the Green River formation above and interfingering with the Wasatch formation. The Green River contains rich oil shales throughout a broad area in northwest Colorado and adjacent territory.

CRETACEOUS SYSTEM

UPPER CRETACEOUS SERIES

Dakota sandstone.—The Dakota sandstone at the base of the Upper Cretaceous section is of importance in this discussion because it is a producing oil and gas horizon in many fields in Wyoming and Colorado. As exposed on Vermilion Creek, twenty miles southwest of Powder Wash, the Dakota sandstone consists of 160 feet of light gray, coarse-grained sandstone and conglomeratic sandstone interbedded with gray-green to dark gray clay shale and carbonaceous shale. Two well developed sandstones, 24 and 50 feet in thickness, respectively, occur near the top and a conglomeratic sandstone about 30 feet in thickness comprises the basal member of the formation. Between the basal conglomeratic sandstone and the upper sandstones is an interval of about 40 feet of dark gray carbonaceous shale and greenish gray shale. Lee[4] states that the Dakota sandstone

> . . . . is believed to be the first sedimentary expression of the sea that invaded the interior of North America about the middle of the Cretaceous period. The sand and pebbles are regarded as coastal plain deposits or in places as the beach deposits of the shore of the advancing sea, and as such they constitute a transgressing formation which may differ slightly in age from place to place.

Near Marshall's Spring, 22 miles southwest of Powder Wash, the basal conglomerate of the Dakota sandstone shows excellent petroleum saturation on its outcrop. The Dakota sandstone is also an important natural gas-producing horizon in the Baxter Basin fields 45 miles northwest of Powder Wash, in Wyoming, and the uppermost oil-producing horizon in the Iles and Moffat domes 56 miles southeast of Powder Wash, in Colorado.

[4] W. T. Lee, "Correlation of Geologic Formations Between East-Central Colorado, Central Wyoming and Southern Montana," *U. S. Geol. Survey Prof. Paper 149*, p. 20.

COLORADO AND MONTANA GROUPS

The term "Mancos shale" generally used in western Colorado stratigraphy to represent that interval between the top of the Dakota sandstone and the basal Mesaverde is not fully satisfactory when applied to northwestern Moffat County, Colorado. It is possible to trace the different stratigraphic units comprising the Colorado and Montana groups of upper Cretaceous age southward from Wyoming into northern Moffat County, Colorado. In 1923, J. D. Sears, J. B. Reeside, Jr., and W. H. Bradley[5] measured the Vermilion Creek stratigraphic section in northwest Moffat County and recognized certain faunal and lithologic subdivisions in the interval between the Dakota sandstone and the Mesaverde formation. However, in conformity with U. S. Geological Survey usage for western Colorado they retained the term "Mancos shale" for the entire thickness of 5,367 feet of shales and sandstones measured between the Dakota sandstone and the Mesaverde formation. The writer is in agreement with John G. Bartram[6] that, inasmuch as northwest Moffat County contains a Cretaceous stratigraphic section that is more representative of Wyoming than of western Colorado in general, the stratigraphic divisions and names of the Wyoming section should be used. Therefore, in Table I the group and formational names representative of the Wyoming section are used. Thus the Colorado group is shown as including the Mowry shale, the Frontier formation, the Carlile shale, and the Niobrara shale, whereas the Montana group is shown as including the Steele shale, the Mesaverde formation, and the Lewis shale.

Mowry shale.—Immediately overlying the Dakota sandstone formation is the Mowry shale, composed of hard, platy marine shales, which have a peculiar silvery appearance on their outcrop and contain abundant fish-scale remains, bone fragments, and teeth. Many well developed beds of bentonite are observed in the Mowry shale section. In the Spring Valley field of southwestern Wyoming oil seepages occur in the Aspen shale, which is the equivalent of the Mowry, and these shales and those of similar age are generally believed to be suitable source rocks for the generation of petroleum throughout Wyoming.

Frontier formation.—Above the Mowry shale in this region occurs the Frontier formation. As exposed on Vermilion Creek the Frontier formation consists of two well developed, fine to medium-grained

[5] J. D. Sears, "Geology and Oil and Gas Prospects of Parts of Moffat County, Colorado, and Southern Sweetwater County, Wyoming," *U. S. Geol. Survey Bull. 751* (1924), pp. 278–79 and 286–89.

[6] John G. Bartram, chairman A.A.P.G. geologic names and correlations committee, personal communication.

sandstones, each exceeding 50 feet in thickness, separated by about 30 feet of gray sandy shale. At the top of the upper sand occur dark carbonaceous shales and some thin coals. The total thickness of the formation is 140 feet. The Frontier formation represents shallow-water off-shore deposition probably of deltaic origin. Marine, brackish-water, and fresh-water fossil remains have been identified from different horizons in the Frontier formation. The Frontier coals and carbonaceous shales with their abundant fossil flora were apparently deposited under widespread paludal conditions protected from the Upper Cretaceous sea. From its type locality in southwest Wyoming the Frontier formation thins out toward the southeast until it apparently disappears in northwest Colorado. The Frontier formation, or its equivalent, produces petroleum and natural gas in many Wyoming fields. The Frontier is an important natural gas-producing formation in the Baxter Basin fields 45 miles northwest of Powder Wash.

Carlile shale.—Above the Frontier formation on Vermilion Creek lies a marine shale section approximately 316 feet in thickness that has been referred to as the Carlile shale. These dark-colored clay shales carrying Carlile fossils are apparently separated from the overlying shale section by a layer of large brown sandstone concretions.

Niobrara shale.—As exposed on Vermilion Creek, a sedimentary thickness of 1,683 feet carries Niobrara fossils and is therefore assigned to the Niobrara shale. Light gray to dark slate-colored marine shales with some interbedded gray, fine-grained, thin sandstones, together with several lines of gray calcareous septarian concretions comprise the Niobrara shale section here.

Steele shale.—A sedimentary thickness of 3,092 feet carrying Montana fossils and lying below the Mesaverde formation on Vermilion Creek is here assigned to the Steele shale. In general the Steele shale is composed of dark gray marine clay shale with several fine-grained, thin, gray sandstone beds near the base and numerous brown sandstone lenses in the upper half of the shale section. Near the top of the Steele shale, as here represented, occur several lines of large, brown calcareous concretions. Selenite crystals are numerous on the weathered shale surface.

In wells drilled in the Steele shale of Wyoming and the equivalent upper Mancos shale of western Colorado there are many "shows" of petroleum and natural gas within this marine sedimentary section although suitable reservoir sands for satisfactory accumulation are lacking. In at least two producing oil fields of minor importance in northwest Colorado, namely Tow Creek and Rangely, the production is from sandy phases and sand lenses in the upper Mancos shale. It is

evident that the marine shale section lying below the Mesaverde formation contains some suitable source beds for the generation of petroleum and natural gas.

Mesaverde sub-group.—The Mesaverde sub-group of northwest Colorado has been divided by E. T. Hancock[7] into two formations, the Iles formation below and the Williams Fork formation above. In Township 10 North, Range 100 West, on the northeast end of the Vermilion Creek exposed section, previously referred to, a well developed fault, described in a previous paper by the writer,[8] offsets Williams Fork sandstone against lower Wasatch shales. Below the partial section of Williams Fork formation exposed against the fault lies a full section of the Iles formation. A deep test well drilled in the Hiawatha gas field in 1933 found the Williams Fork formation apparently present in its full thickness but no indications of petroleum or natural gas were encountered in this formation. No commercial production of petroleum or natural gas is definitely known to occur above the basal sands of the Iles formation of the Mesaverde sub-group in northwest Colorado or southwest Wyoming. At Bellrock and Craig domes in northwest Colorado, 46 miles southeast of Powder Wash, natural gas in fairly large volumes has been encountered in sands designated as basal Iles. However, it is the writer's opinion that the producing gas sands at both Craig and Bellrock are a part of the sandy transition beds of the upper Mancos shale formation, which is the equivalent of the Steele shale of this report, lying immediately below the Iles rather than the true Iles sandstone itself. Whatever the age of the producing beds the source beds can only be the Mancos shale.

Iles formation (*lower Mesaverde*).—Above the Steele shale in the Vermilion Creek section occur 1,650–1,700 feet of light gray, fine to medium-grained massive sandstones with minor amounts of interbedded gray sandy shale and dark carbonaceous shale. Prominent yellow iron stains along fracture planes and ironstone nodules occur in the light-colored, massive sandstones which comprise most of the formation. Marine fossils of Montana age have been identified by the United States Geological Survey[9] in the Iles formation.

Williams Fork formation (*upper Mesaverde*).—Above the massive light-colored sandstones of the Iles formation lie the sandstones, shales, and thin coals comprising the Williams Fork formation. The

[7] E. T. Hancock, "Geology and Coal Resources of the Axial and Monument Butte Quadrangles, Moffat County, Colorado," *U. S. Geol. Survey Bull.* 757 (1925), pp. 13–20.

[8] W. T. Nightingale, *op. cit.* (3), pp. 1030–32.

[9] J. D. Sears, *op. cit.* (5), pp. 289–90.

sandstones of this formation are neither as massive nor as conspicuous in their light coloring as in the underlying Iles formation and the gray shales and coal beds occupy a larger part of the exposed thickness. As exposed southwest of the Sparks fault on Vermilion Creek, only 550 feet of the Williams Fork formation remain. However, as drilled in the deep test well at Hiawatha, 11 miles distant, a full section of some 1,600 feet is believed to be present. No petroleum or natural gas indications are known to the writer to occur in the Williams Fork formation in northwest Colorado or southwest Wyoming.

Lewis shale.—The Lewis shale does not crop out in the Powder Wash area or along Vermilion Creek. However, a very definite thickness of 526 feet of dark gray marine shale was drilled just above the sandstone, shale, and coal section, assigned to the Williams Fork formation, in the Hiawatha deep test well. This thickness of marine shale can only be identified as the Lewis shale. The Lewis shale represents the last definite period of marine shale deposition known to occur in this area. No indications of petroleum or natural gas are known to occur in, or to be associated with, formations immediately underlying or overlying the Lewis shale formation.

Laramie formation.—Above the Lewis shale formation at Hiawatha occur 1,754 feet of massive to thin-bedded, light-colored sandstones, interbedded with dark clay shales, carbonaceous shales, and thin coals, that have been referred to as the Laramie formation. Cores taken in the Hiawatha deep test well indicate an abundant fossil flora in the Laramie formation, particularly in the uppermost 1,200 feet. This formation does not crop out in the Powder Wash area or on Vermilion Creek and its presence in the stratigraphic section of this area, although suspected, was not definitely determined until the deep test well was drilled. The Laramie formation represents the transitional period between the underlying Upper Cretaceous stratigraphic section, largely marine in origin, and the overlying non-marine Tertiary stratigraphic section. No indications of petroleum or natural gas are known to occur in the Laramie formation.

TERTIARY SYSTEM

EOCENE SERIES

Post-"Laramie" formation (Eocene?).—Above the Laramie formation, previously described, and separated from it at Hiawatha by a well developed pebble conglomerate, occur 336 feet of beds termed the post-"Laramie" formation. As drilled in the Powder Wash and Hiawatha areas this formation consists of dark carbonaceous shales and well developed, medium- to fine-grained, gray sandstones. The

sandstones are characterized by numerous very thin partings of carbonaceous and coaly materials. No indications of petroleum or natural gas are known to occur in the post-"Laramie" formation.

Wasatch formation.—The Wasatch formation of the Vermilion Creek area, west of Powder Wash, consists of two stratigraphic units, the Hiawatha member of lower Wasatch age and the Cathedral Bluffs red-bed tongue of upper Wasatch age. Lying between and separating the Hiawatha member from the Cathedral Bluffs tongue in the Vermilion Creek area is the Tipton tongue formation of Green River age. Sears and Bradley[10] have shown how interfingering of the Tipton tongue of the lacustrine Green River formation with Wasatch continental sediments occurred and have satisfactorily explained this apparent anomaly in the Tertiary stratigraphic section.

The Hiawatha member of the Wasatch formation contains the oil- and gas-producing horizons of the Tertiary rocks in this area.

Hiawatha member (lower Wasatch).—The term "Hiawatha member" was assigned to Wasatch strata lying below the Tipton tongue of the Green River formation in the Vermilion Creek basin by the writer[11] in a previous paper. In general, stratigraphic conditions as described in the Vermilion Creek area are applicable to the Powder Wash area which is only 16 miles distant. At Powder Wash the Hiawatha member of the Wasatch formation does not crop out and information regarding it is confined to drill cuttings and cores in the wells drilled. From such information a tentative thickness of 3,535 feet is assigned to the member at Powder Wash. The lithology of the Hiawatha member as drilled at Powder Wash is highly colorful. Variegated shales or mudstones predominate in the section with maroon, brown, pink, grayish green, drab, and other color shades common. In addition, the drilled section shows gray clay shales, gray to drab sandy shales, dark carbonaceous shales, and thin coal beds, as well as numerous irregular, gray to brown sandstones. In character, the sandstones range from medium-grained and tightly cemented to coarse-grained and poorly cemented sandstones or even loose grits. The sandstone beds exhibit extreme lenticularity and are difficult or impossible to correlate, except as to general stratigraphic position, even over short distances. Cross-bedding is pronounced, particularly in the thicker sandstones, and ripple marking is common. Not less than 25 such sandstone horizons, ranging from 7 to 70 feet in thickness, are

[10] J. D. Sears and W. H. Bradley, "Relations of the Wasatch and Green River Formations in Northwestern Colorado and Southern Wyoming," *U. S. Geol. Survey Prof. Paper 132* (1924), pp. 93–107.

[11] W. T. Nightingale, *op. cit.* (3), pp. 1023–25.

known to occur in the Hiawatha member at Powder Wash in addition to many thinner sandstone beds. The more massive sandstones occur in the lower third of the member. No true conglomerates were noted in the drilled section at Powder Wash.

Vertebrate bone fragments and invertebrate fossil shells such as *Unio*, *Viviparus*, *Goniobasis* and *Ostrea* have been noted in the Hiawatha member. The spiral shells of *Goniobasis* are particularly numerous and form marl beds several feet thick in places.

The sediments of the Hiawatha member described are dominantly fluviatile in origin with minor lacustrine and paludal depositional phases evident at wide intervals. The clays and siltstones are for the most part poorly sorted with sandy materials irregularly present. Sharp cleavage planes are notably absent except in certain shale horizons of limited thickness. Local unconformities of variable and limited extent are not uncommon. Alternating color bands are commonly persistent throughout large areas regardless of the lithology. These are common characteristics of fluviatile deposition. However, at intervals throughout this thickness of more than 3,500 feet of the Hiawatha member of the Wasatch formation occur irregular lentils of evenly stratified, well sorted, fissile shales, together with shell beds made up of fresh-water fossil forms that are reasonably believed to represent periods of lacustrine deposition. The thinness of such deposits as compared with the thickness of fluviatile sediments seems to indicate the occurrence of some shallow lakes, comparatively short lived. The occurrence of small amounts of black carbonaceous shale beds together with a few impure, low-grade lenticular coal beds is ascribed to rare paludal or intermittent swamp conditions occurring on the old Wasatch flood plain.

The oil- and gas-producing sands at Powder Wash occur in the Hiawatha member of the Wasatch formation. Petroleum in commercial amounts has been found in one well near the base of the Hiawatha member, approximately 5,300 feet below the Laney shale-Cathedral Bluffs contact, and in a second well at 3,350 feet below that contact. Thus the stratigraphic interval between the two petroleum-producing horizons is 1,950 feet. A considerable interval also is present between the two gas-producing sands for the two completed gas wells produce from two separate horizons approximately 2,350 and 3,400 feet, respectively, below the same Laney shale-Cathedral Bluffs contact. Porosity values in the producing sands at Powder Wash vary from 14.97% to 21.4%.

Cathedral Bluffs tongue (*upper Wasatch*).—Above the Hiawatha member of the Wasatch formation lies the Cathedral Bluffs tongue of

that formation. Red, purple, and brown clay shales with thin, reddish to gray sandstones comprise the greater part of the Cathedral Bluffs tongue on its outcrop west of Powder Wash. A few lighter bands of light green to gray shale occur at intervals but the general color is conspicuously reddish. As drilled at Powder Wash the reddish coloration still predominates but more gray to drab clay shale is present than in the outcrop. It appears probable that, where examined on the outcrop, the originally less vividly colored sediments of the Cathedral Bluffs tongue have been stained reddish or purplish from the erosion of the adjacent red-colored beds. As measured in the field the total thickness of beds assigned to the Cathedral Bluffs member is 1,750 feet. However, as drilled at Powder Wash, this thickness is believed to be approximately 1,850 feet. No indications of petroleum or natural gas occur in the Cathedral Bluffs tongue at Powder Wash.

Green River formation (*Middle Eocene*).—The Green River formation of this area is divided into two stratigraphic units, the Tipton shale tongue (lower Green River) and the Laney shale member (upper Green River).

Tipton shale tongue (*lower Green River*).—The Tipton shale tongue as examined where it crops out 14 miles west of Powder Wash is a thin-bedded, fissile, somewhat bituminous shale of lacustrine origin that has a peculiar and distinctive bluish gray cast on its weathered surface. As previously mentioned in this paper,[12] the Tipton shale tongue of the Green River formation, by an unusual case of regional interfingering, divides the Hiawatha member (lower Wasatch) from the Cathedral Bluffs member (upper Wasatch).

At Powder Wash the Tipton shale tongue of the Green River formation does not crop out. However, in the well drilled at Powder Wash there is some reason to believe that 75 feet of dark shale drilled 1,850 feet below the Laney shale-Cathedral Bluffs contact may represent the Tipton shale tongue. If this interpretation is correct it would indicate a considerable thinning of the Tipton shale tongue, from 367 feet, where measured fourteen miles west of the Powder Wash field, to 75 feet in the field.

Laney shale member (*upper Green River*).—Overlying the Cathedral Bluffs member of the Wasatch formation is the Laney shale member of the Green River formation of Middle Eocene age. First named by F. V. Hayden[13] in 1869, the shales of the Green River formation, chiefly represented by the Laney shale member in the Powder Wash area, have been of great interest geologically because of their bituminous

[12] J. D. Sears and W. H. Bradley, *op. cit.* (10), pp. 93–107.

[13] F. V. Hayden, *U. S. Geol. Survey Terr. Third Ann. Rept., 1869.*

content. The bitumens are present in the form of complex organic compounds and are available only through destructive distillation. In the Powder Wash area the Laney shale member of the Green River formation consists of gray to drab, finely laminated, fissile shale, gray clay shale or siltstone, and bituminous shale, together with several thin sandstones and a few well developed and massive sandstones near the top and near the base of the formation. Some interesting occurrences of silicified oölitic beds and calcareous algal reefs have also been noted. The grayish blue bluffs of the Laney shale member are particularly distinctive as contrasted with the reddish coloring of the underlying Cathedral Bluffs tongue of the Wasatch formation. W. H. Bradley[14] has defined the oil shale as follows.

> Oil shale is a fine-grained sedimentary rock containing organic matter which was derived chiefly from aquatic organisms or waxy spores and pollen grains, which is only slightly soluble in ordinary petroleum solvents, and of which a large proportion is distillable into artificial petroleum.

As a result of a microscopic study of the bituminous shales of the Green River formation Charles A. Davis[15] states:

> The inference is clear that the structureless material probably originated in a collection of plant debris which has by decomposition and the activities of bacteria and other microscopic oganisims passed into a jelly-like phase such as is to be found in certain kinds of modern peat deposits. The plant remains that have been found in the shale from every locality which has furnished samples are those of microscopic algae mixed in smaller percentages with pollen and similar parts of higher plants. Animal remains are rare in the material studied, and those noted were chiefly the remains of insects in a very fragmental state.
>
> It seems apparent, therefore, that the study of the microscopic structure of this shale as seen in vertical and horizontal sections leads to the conclusion that the material was laid down originally in water and that it passed through a series of stages of decomposition before consolidation and lithification had taken place. The remarkably well preserved state of the delicate plant structures which have been examined indicates very slight disturbances of the original material and an almost entire lack of changes produced by the action of the usual metamorphosing agencies since lithification.

Whereas less than 25% of the 1,200 feet of sediments assigned to the Laney shale member of the Green River formation in that part of northwest Colorado and southwest Wyoming adjacent to Powder Wash can be classified as true oil shales, nevertheless the presence of such shales overlying the Cathedral Bluffs tongue of the Wasatch formation is worthy of mention in this discussion.

[14] W. H. Bradley, "Origin and Microfossils of the Oil Shale of the Green River Formation of Colorado and Utah," *U. S. Geol. Survey Prof. Paper 168* (1931), p. 7.

[15] D. E. Winchester, "Oil Shale in Northwestern Colorado and Adjacent Areas," *U. S. Geol. Survey Bull. 641-F* (1916), p. 165.

Bridger formation (*Middle Eocene*).—At Powder Wash the Bridger formation, which normally overlies the Laney shale member of the Green River, is missing as a result of erosion. However, in the Washakie Basin, on the north, and the Sand Wash Basin south of Powder Wash several hundred feet of Bridger fluviatile and lacustrine sediments occur. Gray and greenish gray, ashy, clay shales, sometimes red banded, together with soft, gray sandstones, and fresh-water limestones here comprise the Bridger formation. A wide and varied mammalian fossil fauna has been found in this formation. No indications of petroleum or natural gas are known to occur in the Bridger formation and any further detailed discussion of the formation is not believed pertinent to the subject of this paper.

MIOCENE (?) SERIES

Brown's Park formation (*Miocene?*).—Both north and south of the Powder Wash field a few remnants of the Brown's Park formation remain. In this area the Brown's Park formation consists of a basal conglomerate overlain by massive, gray to white, cross-bedded, wind-blown sandstone and some tuffaceous beds. Volcanic ash occurs as a constituent of the sandstones. Although the problems associated with the Brown's Park formation are of considerable stratigraphic interest they are not pertinent to this paper.

STRUCTURE

The structure of that part of northwest Colorado in which the Powder Wash area is located is comparatively simple. The Powder Wash dome, together with associated uplifting, forms the structural divide between the Washakie Basin on the north, in Wyoming, and the Sand Wash Basin on the south, in Colorado.

North and northeast of Powder Wash occurs a line of folding and faulting developed in Brown's Park, Green River, and Wasatch beds, all of Tertiary age, that is referred to as the Cherokee Ridge upfold. This line of folding and faulting extends in an east-west direction immediately north of the Colorado-Wyoming state line (Fig. 1). Southwest of Powder Wash lies the Dry Mountain-Two Bar line of folding and faulting likewise developed in Brown's Park, Bridger, Green River, and Wasatch beds. The Dry Mountain-Two Bar line of folding and faulting extends from northwest to southeast and is believed to represent a continuation of the Uinta Mountain north frontal faulting (Fig. 1). The deformation, both folding and complex faulting, noted in the Cherokee Ridge and the Dry Mountain-Two Bar faulted upfolds, is believed to be the expression in Tertiary beds of more severe

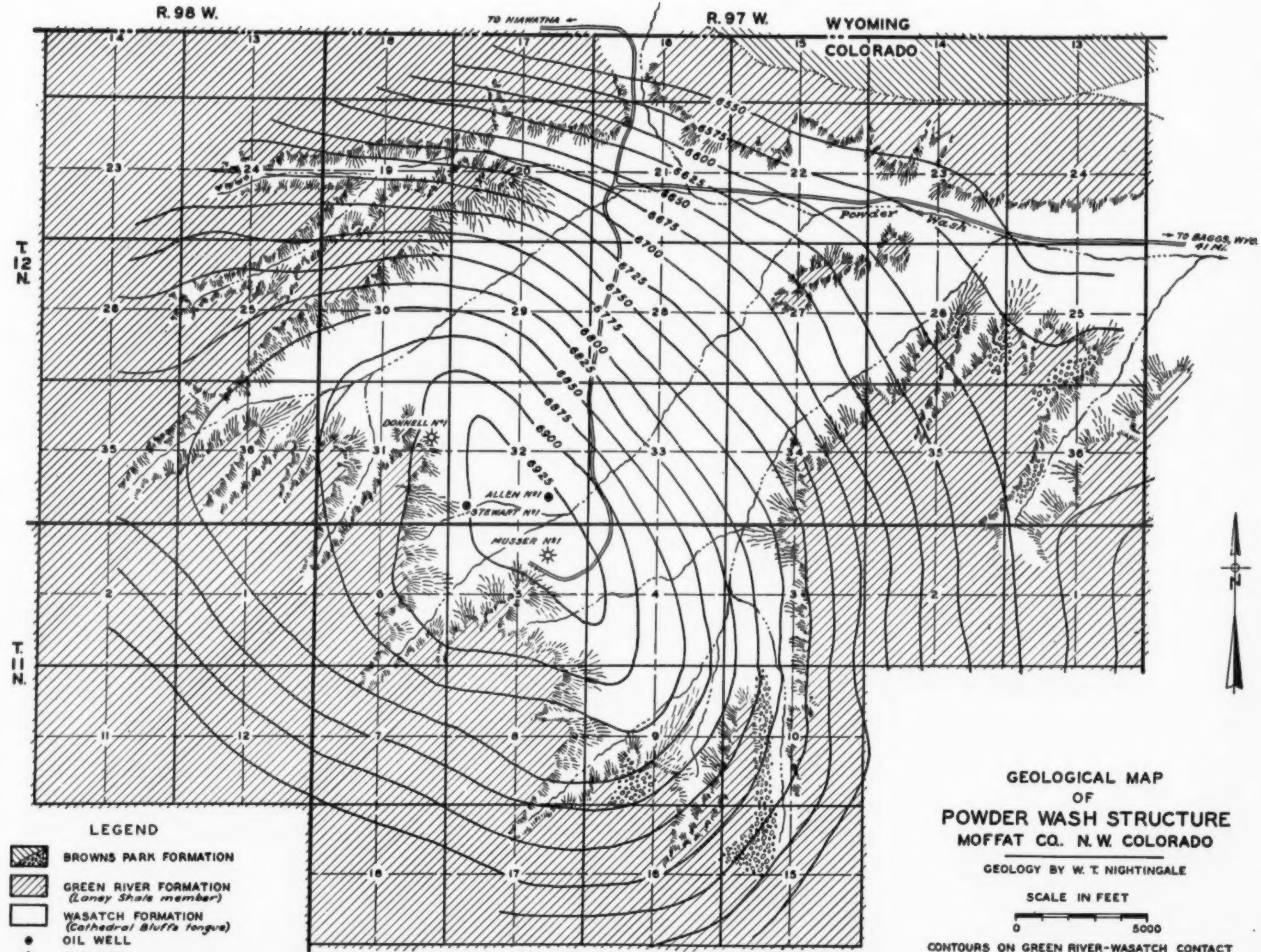

R. 98 W.
R. 97 W.
WYOMING
COLORADO
TO HIAWATHA
TO BAGGS, WYO. 41 MI.
Powder Wash
T. 12 N.
T. 11 N.
6550
6575
6600
6625
6650
6675
6700
6725
6750
6775
6800
6825
6850
6875
6900
6925
DONNELL Nº1
ALLEN Nº1
STEWART Nº1
MUSSER Nº1
N
LEGEND
BROWNS PARK FORMATION
GREEN RIVER FORMATION
(Laney Shale member)
WASATCH FORMATION
(Cathedral Bluffs tongue)
OIL WELL
GAS WELL
GEOLOGICAL MAP
OF
POWDER WASH STRUCTURE
MOFFAT CO. N. W. COLORADO
GEOLOGY BY W. T. NIGHTINGALE
SCALE IN FEET
0
5000
CONTOURS ON GREEN RIVER-WASATCH CONTACT

FIG. 2

fracturing, faulting, and possibly folding, in the older underlying formations. This older period of deformation of the pre-Tertiary rocks in both the Dry Mountain-Two Bar and Cherokee Ridge lines of folding and faulting is probably of late Cretaceous age and contemporaneous with Uinta Mountain orogeny. Whether or not the late Cretaceous structural movement represents the original deformation or whether it is a revival along still older lines of weakness has not yet been determined satisfactorily.

The Powder Wash structural dome is believed to have had its origin in compressional forces set up by a revival in Eocene time of deformation along the older lines of weakness in the Dry Mountain-Two Bar and Cherokee Ridge folded belts. A final period of movement in post-Miocene time, which deformed Brown's Park beds, completed the folding at Powder Wash.

The Powder Wash structure is that of a broad, gently folded, unfaulted dome. Less than 100 feet of closure is evident from surface mapping, although there is reason to believe, from a tentative correlation of beds in the drilled wells, that folding may become somewhat more pronounced with depth. The surface structure includes some 4,500 acres within the limits of closure. Excellent control for mapping the broader structural features at Powder Wash is afforded by well developed and resistant beds at or near the contact of the Laney shale member of the Green River formation and the underlying Cathedral Bluffs tongue of the Wasatch formation. An examination of the very conspicuous rim-rocks which almost encircle the Powder Wash dome reveals a complete absence of faulting that is most remarkable for a Rocky Mountain structure. This complete absence of fracturing and faulting at Powder Wash is important in this discussion in that the possibility of petroleum or natural gas migration across the stratigraphic section and into the sands of the Hiawatha member of the Wasatch formation from either younger or older beds by way of fracture zones and subsequent channels within the field can not be supported by field evidence.

Water

The occurrence of saline waters associated with the petroleum-producing horizons at Powder Wash is of particular interest. Analyses of waters taken during the drilling operations at Powder Wash show waters ranging from fresh to brackish to definitely saline in composition. So far as known the sands encountered in the uppermost 2,000 feet of drilling contain water which is comparatively fresh in character. Below that depth and in the Hiawatha member of the Wasatch

brackish-water horizons increase in number. However, waters associated with the two oil-saturated zones discovered at Powder Wash show a heavy increase in the chloride content and a very noticeable decrease in the sulphate content as compared with waters from the barren sands. The increased chloride content and reduced sulphate content of the waters does not appear to be a function of depth but rather is due to association with petroleum-saturated horizons. The reduction of the sulphates in the oil-saturated zones at Powder Wash may be due to the action of micro-organisms in the decomposition of organic matter.

Four typical analyses made by the United States Geological Survey laboratory at Midwest, Wyoming, are as follows.

POWDER WASH FIELD WATER ANALYSES

Sample I—700-foot Level, Barren Zone

Parts per million 1,122 (calculated)

Radicals	(Na & K)	(SO_4)	(Cl)	(CO_3)	(H CO_3)
Parts per million	399	522	39	Tr.	330
Reacting value	17.38	..87	1.10	—	5.41
Value in percentage	50.00	31.27	3.17	—	15.56

Primary salinity	68.88%
Secondary salinity	0.00%
Primary alkalinity	31.12%
Secondary alkalinity	0.00%

Sample II—3,075-foot Level, Petroleum Zone

Parts per million 17,773 (calculated).

Radicals	(Na & K)	(Ca)	(Mg)	(SO_4)	(Cl)	(H CO_3)
Parts per million	6,406	368	133	—	10,584.	575
Reacting value	278.68	18.36	10.93	—	298.55	9.42
Value in percentage	45.24	2.98	1.78	—	48.47	1.53

Primary salinity	90.48%
Secondary salinity	6.46%
Primary alkalinity	0.00%
Secondary alkalinity	3.06%
Chloride salinity	100.00%
Sulphate salinity	—

Sample III—4,950-foot Level, Barren Zone

Total parts per million 6,000 (calculated).

Radicals	(Na & K)	(SO_4)	(Cl)	(CO_3)	(H CO_3)
Parts per million	2,389	103	2,964	350	395
Reacting value	103.90	2.14	83.61	11.67	6.48
Value in percentage	50.00	1.03	40.23	5.62	3.12

Primary salinity	82.52%
Secondary salinity	00.00%
Primary alkalinity	17.48%
Secondary alkalinity	0.00%
Chloride salinity	97.52%
Sulphate salinity	2.48%

Sample IV—5,218-foot Level, Petroleum Zone

Total parts per million 16,379 (calculated).

Radicals	(Na & K)	(Ca)	(SO_4)	(Cl)	(OH)
Parts per million	5,838	573	137	9,516	31
Reacting value	253.96	28.60	2.85	268.42	1.82
Value in percentage	44.94	5.06	0.50	47.50	0.32

Primary salinity	89.88%
Secondary salinity	6.12%
Primary alkalinity	17.48%
Secondary alkalinity	0.00%
Chloride salinity	97.52%
Sulphate salinity	2.48%

Although the saline waters associated with the two petroleum zones at Powder Wash are considerably more dilute than normal ocean water, yet these oil-field waters are more saline than the waters of most closed basins of the present time.[16] Furthermore, the Powder Wash petroleum-zone waters are more saline than the great majority of oil-horizon waters throughout the Rocky Mountain fields as shown by Coffin and DeFord.[17]

Petroleum

The analyses of petroleum samples taken from the two producing horizons at Powder Wash indicate a close similarity in composition although a stratigraphic interval of some 1,950 feet intervenes between the two horizons. The crude oil is of an intermediate-paraffin base and contains a very considerable amount of wax. A pour point of 80°F. makes transportation difficult, particularly in cold weather. Both the sulphur content and the carbon residue are very low and it is believed the oil may have lubricating possibilities. Type analyses of the crude oil from the Hal W. Stewart well No. 1 at 3,087 feet and the Carl Allen well No. 1 at 5,014 feet are as follows.

HAL W. STEWART WELL NO. 1

3,087 feet

Specific gravity	.834	A.P.I. gravity	38.2°
Sulphur less than	0.1%		
Pour point	80°F.		
Color	Green		
Saybolt Universal viscosity at 100°F.		36 sec.	

Distillation Summary

	Per Cent
Gasoline and naphtha	35.1
Kerosene distillate	9.0
Gas oil	20.9
Nonviscous lub. distillate	17.5
Medium lub. distillate	0.6
Residuum	15.5
Distillation loss	1.4
Carbon residue	3.8

[16] F. W. Clarke, "Data of Geochemistry," *U. S. Geol. Survey Bull.* 770 (1924), pp. 156–80.

[17] R. Clare Coffin and R. K. DeFord, *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), pp. 927–52.

CARL ALLEN WELL NO. 1

5,014 feet

Specific gravity	.838	A.P.I. gravity	37.4°
Sulphur less than	0.1%		
Pour point	80°F.		
Color	Green		
Saybolt Universal viscosity at 100°F.		39 sec.	

Distillation summary

	Per Cent
Gasoline and naphtha	25.5
Kerosene distillate	19.5
Gas oil	14.5
Nonviscous lub. distillate	18.3
Medium lub. distillate	0.8
Residuum	19.9
Distillation loss	1.5
Carbon residue	3.8

Natural Gas

Whereas the occurrence of petroleum in the non-marine sediments of the Wasatch formation at Powder Wash has evoked much geological comment, the presence of natural gas in different horizons and showing very different analyses is no less interesting.

As hereinbefore mentioned, the discovery well at Powder Wash, the B. W. Musser No. 1, was completed as a 34,000,000 cubic feet gas well in the upper part of the Hiawatha member of the Wasatch formation. An analysis of the gas from this well is shown in the following gas sample No. 1.

		Per Cent
Methane (CH_4)		95.9
Ethane plus (C_2H_6+)		0.7
Carbon Dioxide (CO_2)		0.3
Hydrogen Sulphide (H_2S)		.007
Oxygen (O_2)		.5
Nitrogen (N_2)		2.5
Specific gravity (calculated)	0.574	
B. T. U. (calculated)	980	

A natural gas sample from a sand encountered at 3,059 feet in the Carl Allen well No. 1 at Powder Wash was analyzed as shown in the following gas sample No. 2.

		Per Cent
Methane (CH_4)		92.58
Ethane (C_2H_6)		5.70
Propane (C_3H_8)		0.21
Butane (C_4H_{10})		0.21
Pentanes and heavier		1.30
Specific gravity (calculated)	.613	
B. T. U. (calculated)	1,102	

Both of the foregoing analyses are of gases encountered in two different sand horizons in the Hiawatha member of the non-marine Wasatch formation at Powder Wash. Approximately 1,200 feet of stratigraphic interval separate the two sands which contain the natu-

ral gases described. A wide variance in composition, specific gravity, and heat value is readily apparent in the two analyses.

The gas analysis of sample No. 1, from the B. W. Musser well No. 1, is apparently a dry gas and disassociated from any known petroleum horizon. However, the gas analysis of sample No. 2, from the Carl Allen well No. 1, is definitely associated with some petroleum saturation and saline water lower in the same sand.

The occurrence of a very small amount of hydrogen sulphide (H_2S) in sample No. 1 is particularly interesting in that it is the only such occurrence noted in the Wasatch gas-producing areas of northwest Colorado. In the Green River formation[18] and in lacustrine phases of the Wasatch formation the presence of iron disulphide has been detected in the form of pyrite and, in a lesser amount, as marcasite. The presence of pyrite and marcasite in these Tertiary sediments probably indicates that during the process of putrefaction of organic materials in Tertiary lake bottoms a considerable amount of hydrogen sulphide (H_2S) was set free. Some free hydrogen sulphide would react with any iron salts in solution in the lake waters to form iron disulphides such as pyrite and marcasite. Some of the free hydrogen sulphide might be expected to escape through the lake waters into the atmosphere but a very considerable amount might also be expected to remain confined in the organic ooze in which it was formed. Succeeding sedimentary deposits would more thoroughly confine this part of the hydrogen sulphide gas until such time as sedimentary compaction would force its migration into adjacent porous horizons where it would mix with and contaminate the gaseous hydrocarbons.

Discussion

A critical examination of all evidence pertaining to the problem of the occurrence of petroleum and natural gas in the non-marine sediments of the Hiawatha member of the Wasatch formation at Powder Wash indicates that these hydrocarbons are indigenous to the formation in which they are found. The Powder Wash dome is a gentle and regular upfold with no indication of any faulting or fracturing on the structure or in the general area that could in any way be interpreted as channel forming for the vertical migration of any hydrocarbons from younger or older formations into the present producing reservoir sands of the Hiawatha member of the Wasatch formation.

The overlying Laney shale member and the interfingering Tipton shale tongue of the lacustrine Green River formation, although highly

[18] W. H. Bradley, *op. cit.* (14), pp. 30–31.

organic, are not considered as possible source beds for the Wasatch oil largely because of the character of the organic materials held in the shales. By far the greater part of the organic matter of the Green River shales can be transformed into crude oil and associated products only through the process of destructive distillation. There is no evidence to support any assumption that such distillation has been effective in the Green River shales since they were deposited in Middle Eocene time. In fact, it is probable that essentially the entire original organic content of the Green River shale formation is still held within the shales in the area north and northeast of the Uinta uplift. If this is true these shales can not have been the source of oil found in the underlying Wasatch formation, Furthermore, the entire section of the Cathedral Bluffs tongue, comprising some 1,800 feet of sediments and including several porous sandstones, lies between the Laney shale member of the Green River oil shales and the Hiawatha productive member of the Wasatch formation. Likewise approximately 1,200 feet of the upper Hiawatha member intervenes between the Tipton shale tongue of the Green River formation and the highest productive petroleum horizon in the Hiawatha member. No indications of petroleum are known to occur in the Cathedral Bluffs member or the upper several hundred feet of the Hiawatha member.

Immediately underlying the Hiawatha member of the Wasatch formation in the Powder Wash area is a "Laramie"-post-"Laramie" section that is considered most unlikely as a generative source for petroleum or natural gas. The shales of this stratigraphic section contain much carbonized wood and thin coal bands are very numerous. The sandstones are conspicuous and well developed and should make excellent reservoir sands for petroleum or natural gas if the interbedded carbonaceous shales had been suitable source sediments. It is not reasonable to assume that the "Laramie" shales could have been satisfactory source sediments for petroleum and natural gas in this area and that following generation these hydrocarbons could possibly have migrated vertically across a maximum of 2,090 feet of a stratigraphic section, comprising many excellent porous sandstones, and into an overlying formation, leaving no indications in the porous beds necessarily traversed.

Below the "Laramie" formation in this area lies the Lewis shale formation of marine origin. There is no evident reason why the marine clay shales of the Lewis formation should not have been satisfactory source beds in the formation of petroleum and natural gas. However, no indications of oil or gas have been found in the Lewis shale formation or in the well developed sandstones of the "Laramie" formation

above or the Mesaverde formation below the Lewis shale formation. To have reached the Hiawatha member of the Wasatch formation by vertical migration, any hydrocarbon that might have originated in the Lewis shale would have to traverse the full "Laramie"-post-"Laramie" section of 2,090 feet with its numerous sandstones capable of being excellent reservoirs for the accumulation of oil and gas. No evidence obtained, either through field examinations or by deep well drilling on closed structures, supports in any respect such an assumption of vertical migration from a source in the Lewis shale.

Below the Lewis shale in the stratigraphic section lie the Mesaverde formation, the Steele shale, the Niobrara shale, the Carlile shale, the Frontier formation, the Mowry shale, and the Dakota sandstone, respectively. These formations are hereinbefore described under their respective headings in the description of the stratigraphy of the Powder Wash region in this paper. Any assumption of vertical migration from these lower formations is confronted by the objections already mentioned. No such assumption is tenable in accounting for the presence of petroleum and natural gas in the Hiawatha member of the Wasatch formation.

To postulate long-distance lateral migration into the lower Wasatch sands at Powder Wash requires the assumption that vertical migration must first have occurred upward along fault or fracture channels developed somewhere in the Wasatch formation. It must also necessarily be assumed that any such vertical migratory movement must have terminated somewhere down dip in the basin tributary to Powder Wash, as a careful field examination reveals no faulting or fracturing in the vicinity of Powder Wash dome. It must then be further assumed that long-distance lateral migration up the dip through porous media has occurred to provide the present known accumulation in the crest of the structure. Such a series of assumptions is untenable. As first discussed under the heading "Structure" in this paper, the only faulted or fractured zones in the general region that could have acted as migratory channels for a vertical movement of petroleum or natural gas are the faults and fractures known to occur along Cherokee Ridge, 10 miles northeast of Powder Wash, or the faults and fractures in the Dry Mountain-Two Bar area, 22 miles southwest of Powder Wash. A test well drilled through the entire Wasatch section on Cherokee Ridge failed to find any indications of petroleum in the Wasatch beds and a test well drilled 3,003 feet into the Wasatch section failed to find either oil or gas at Dry Mountain. If the faulting and fracturing apparent in the Cherokee Ridge and Dry Mountain areas had effectively provided migratory chan-

nels for upward migration into the Wasatch formation from pre-Tertiary horizons it would not be unreasonable to expect some indication of petroleum or natural gas in the Wasatch beds in the test holes drilled there. No such indications have been found. To postulate lateral migration for any considerable distance through porous media in the Wasatch formation is to fail in recognizing the extremely lenticular and even erratic character of the arenaceous sediments in the continental Wasatch formation. Porous horizons of any considerable uninterrupted lateral extent have not been recognized in the outcrops of the Wasatch formation of this region and have not been encountered in drilling. In the writer's opinion, long-distance lateral migration as a function of accumulation can not be supported at Powder Wash.

HYDROCARBON ORIGIN AT POWDER WASH

From the foregoing discussion it is evident that we must look to the Hiawatha member of the Wasatch formation itself for the source as well as the present reservoir of the petroleum and natural gas found at Powder Wash. Admittedly, in the light of present geologic thought on the origin of petroleum, continental sediments such as comprise the Wasatch formation are generally considered unfavorable as a generative source of hydrocarbons. Yet all available evidence assembled on this problem at Powder Wash indicates that petroleum and natural gas in fairly large volumes are apparently indigenous in a formation of continental origin. Certainly there is nothing in the sedimentation of the Wasatch formation, either at Powder Wash or elsewhere throughout the Rocky Mountain region, that would suggest its being of marine origin.

The sediments comprising the Tertiary formations of the Green River drainage basin and its subordinate structural divisions were supplied by the surrounding orogenic belts which attained mountainous proportions during late Cretaceous or Paleocene time. The Uinta Mountains, which lie immediately adjacent to the area under discussion herein (Fig. 1), probably furnished the greater part, if not all, of the sediments which now comprise the Wasatch formation in the Powder Wash area.

Forrester[19] states:

> Field data indicate three major periods of diastrophic activity in the Uinta Mountains, and these have been responsible for a maximum vertical uplift of approximately 45,000 feet in the center of the range; that is, the lower beds of the Uinta Series, which were covered by 35,000 feet of shallow water sediments, now stand 10,000 feet above sea level.

[19] J. D. Forrester, "Structure of the Uinta Mountains," *Bull. Geol. Soc. America*, Vol. 48 (1937), pp. 648–49.

The sediments removed by erosional activity from the Uinta Range have been deposited in the adjacent basins since earliest Eocene time. Thousands of feet of shales, sandstones, and limestones, ranging in age from Cambrian to Upper Cretaceous, were eroded from the Uinta Mountains and transported into the adjacent basins to form a thick, Tertiary stratigraphic section of 5,000 to 8,000 feet. Other ranges surrounding the present Green River drainage basin also contributed great volumes of sediments during Eocene time, but because of its immediate proximity the Uinta Uplift was probably the main source of sediments in the Powder Wash area. Conglomerates are not uncommon in the Wasatch stratigraphic section near the mountains but they are completely lacking at Powder Wash and the sedimentary sorting becomes much better and more complete away from the Uinta mountain source of the rock materials.

Although Wasatch sedimentation is dominantly of the fluviatile type, yet shallow lakes of limited lateral extent apparently were not uncommon on the early Eocene flood plains of this region. A comparatively high rate of evaporation necessary to account for the saline waters now found in the Wasatch formation would indicate arid climatic conditions during Wasatch time.

F. W. Clarke[20] has said:

> Wherever sediments are laid down, inclosing either animal or vegetable matter, there bitumens may be produced. The presence of water, preferably salt, the exclusion of air, and the existence of an impervious protecting stratum of clay seem to be essential conditions toward rendering the transformation possible.

It would appear that in Wasatch time these conditions may have been at least occasionally fulfilled during the deposition of continental sediments in the Powder Wash region.

The presence of shallow lakes or limited barred basins at infrequent intervals on the Wasatch flood plain was quite possible. Such catchment basins could have served as repositories for considerable quantities of organic materials. Protection from the larger flood-plain streams, for at least sufficient time to allow for burial of the decomposing organic materials, is suggested by the connate saline waters now found associated with the petroleum-saturated horizons, as fresh-water streams constantly flowing into or through such basins of limited extent would have precluded any possibility of the basin waters retaining their salinity.

No evidence is yet available regarding the types of organic materials most abundant and most suitable for petroleum and natural gas

[20] F. W. Clarke, *op. cit.* (16), p. 754.

generation in the Wasatch shales associated with the producing horizons at Powder Wash. These shales are noticeably barren of organic fossil remains at the present time. If the Wasatch shales are the source beds, then the generative organic materials were probably of the soft body types that were completely transformed during the process of generation. No megascopic fossil remains are known to be present in the Wasatch shales associated with the present producing horizons and insufficient microscopic work has been done on them to shed any light on possible micro-organism remains.

Some consideration has also been given to the possible deposition of the oil at Powder Wash as a sediment in itself. Murray Stuart[21] has suggested a transportation theory to account for the presence of petroleum deposits under certain conditions in Burma. He noted that where petroleum was poured out on the surface of a muddy stream it persisted for only a comparatively short distance on the surface of the water and the stream soon appeared clear again. Laboratory experiments performed by Stewart indicated that a very considerable quantity of petroleum can be carried down by gravity in the settling of fine-grained sediments. In fact, it was found by experimenting that one volume of fine sediment, measured after consolidation, could, by mechanical mixture, settle out an equal volume of very light oil. Stewart states:

> The sedimentary deposition of oil, therefore, is not only a possibility that is capable of mechanical proof but investigation shows that it may be purely a matter of gravitation. The oil becomes mechanically mixed with the sediment, and the fineness of that sediment renders it impossible for the oil to become demulsified, and the mixture of sediment and oil globules being still, as a whole, of higher specific gravity than water, falls to the bottom and is deposited as a sedimentary deposit.

In this manner a deposit of fine mud containing innumerable oil globules would result. Changing conditions of sedimentation could deposit sands above such petroleum-carrying muds. If the original and older reservoir source of the petroleum should be completely destroyed by continued erosion, muds and sands higher in the newly formed stratigraphic section would be barren of petroleum until such time as another and older petroleum-bearing horizon should be opened by erosional activities to again contribute sedimentary oil to a younger forming stratigraphic section.

On the northeast flank of the Uinta Mountain uplift, where the entire stratigraphic section from Upper Cretaceous to pre-Cambrian is

[21] Murray Stuart, "The Geology of Oil, Oil Shale and Coal," *Mining Publications Ltd.*, London (1926), pp. 7–16.

well exposed, several pre-Tertiary horizons that are known petroleum reservoirs in Wyoming and Colorado were deformed by the Uinta orogenic movements and dissected by subsequent erosional activity. The Dakota sandstone, in particular, because of its saturation on a faulted and eroded outcrop only 22 miles southwest of Powder Wash, could well have poured petroleum from its broken reservoir into streams crossing the Wasatch floodplains to be deposited as a sediment under favorable conditions. Likewise the Jurassic Sundance formation, which is productive of petroleum in northwest Colorado, could have been the source of petroleum for a higher Wasatch saturated horizon. As yet insufficient evidence is at hand fully to support this theory of petroleum depositon as a sediment at Powder Wash, but it does offer a hypothesis worthy of additional investigation.

FIELD DEVELOPMENT PROBLEMS

The extreme lenticularity of reservoir sands in fields of continental deposition, such as Powder Wash, adds greatly to the normal drilling hazards. Producing fields developed under such sedimentary conditions may well have a much higher percentage of non-productive holes within the high structural area than do fields in which sheet sands form the producing reservoir. An understanding of the paleogeography, the source of the sediments, the direction of their movement, and the character of the transporting agent, all help in determining, to some extent, the general shape of the sand lenses. Unfortunately these factors have not yet been determined locally with sufficient accuracy to eliminate an unusual amount of risk in the development of Tertiary non-marine petroleum and natural gas fields in northwest Colorado and adjacent territory. A regular pattern of predetermined drilling locations such as is common in many producing fields would be wholly unsuited to a field like Powder Wash. On the contrary, each well drilled and the information obtained therefrom, particularly as to the exterior form of the sand lenses, influences the succeeding location. As finally drilled, the producing pattern of the wells is more likely to form irregular belts across the structure in the direction of the greatest linear extent of each reservoir sand lens.

CONCLUSIONS

From the foregoing facts the following conclusions are reached.

1. The petroleum and natural gas found in the non-marine sediments of the Powder Wash field are indigenous to the Wasatch formation in which they are found.

2. Any hypotheses involving either vertical or long-distance lat-

eral migration of petroleum or natural gas into the present reservoir sands from any distant sources are quite untenable.

3. Accumulation is controlled by domed folding modified by the shape and continuity of lenticular sands within the confines of the fold.

4. The petroleum and natural gas fields developed in continental sediments such as the Wasatch formation of the Rocky Mountain region involve greatly increased drilling hazards because of (a) the irregular and uncertain conditions of hydrocarbon generation, and (b) the extreme lenticularity of reservoir sands.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 1048-1079, 7 FIGS.

WILMINGTON OIL FIELD, LOS ANGELES COUNTY, CALIFORNIA[1]

E. J. BARTOSH[2]
Los Angeles, California

ABSTRACT

The Wilmington oil field, located 20 miles south of Los Angeles and adjacent to the Los Angeles Harbor, is one of the largest oil fields discovered in California.

Oil was first produced in January, 1932, from the Lower Pliocene formation. The General Petroleum Corporation's Terminal No. 1 was the first large well and was completed in December, 1936, with an initial production of 1,500 barrels per day, 20.5° A.P.I. gravity, from the Puente formation (Upper Miocene) at a depth of 3,625 feet.

Discovery was made by correlation of outpost wells together with a seismograph survey which added materially to the general outline of the structure.

The structure is an irregular-shaped dome with faulting transverse to the principal axial trend. The dip of strata ranges from 2° to 15°.

The major faulting apparently occurred near the close of Miocene time and continued progressively throughout deposition of the Repetto formation (Lower Pliocene).

Production is obtained from the Repetto formation (Lower Pliocene) and the Puente formation (Upper Miocene).

There are five producing zones: Tar, Ranger, upper Terminal, lower Terminal, and Ford.

The gravity of oil ranges from 12° to 31°. The lower 700–800 feet of Pliocene and 2,500 feet of Miocene formation contain oil and gas at different stratigraphic levels.

The field has produced a total of 17,608,495 barrels of crude oil from discovery date, December 7, 1936, to February 15, 1938, inclusive.

Recent development in the City of Long Beach has increased the proved area from 2,100 acres to 3,200 acres.

Production on March 2, 1938, was 101,382 barrels daily from 374 wells with a large part of proved area undeveloped.

INTRODUCTION

The Wilmington oil field is one of the largest oil fields discovered in California, and from December 6, 1936, to February 15, 1938, 389 wells have been completed, which indicate the rapidity of development. Drilling activity is again on the upward trend since November 11, 1937, when restrictions were lifted on properties located in the City of Long Beach. Production of early outpost wells has shown considerable decline, although considering the type of oil zone and structural position, the average of all wells is very steady.

The field is producing oil from the lower 700 feet to 800 feet of Repetto (Lower Pliocene), and from different parts of the upper 2,500 feet of Puente (Upper Miocene) formations which are of the same age as formations producing gas and oil at Torrance, El Segundo, Del Rey, or the coastal fields of the Los Angeles Basin. All of these fields are underlain by schist.

[1] Read before the Association at New Orleans, March 17, 1938. Manuscript received, May 10, 1938.

[2] Bankline Oil Company, 634 South Spring Street.

A brief summary is given of the geology, stratigraphy, and history of development in the field to February 15, 1938, and the subsurface conditions shown as they are known at the present time.

LOCATION AND DISCOVERY

The Wilmington oil field, located 20 miles south of Los Angeles and contiguous to Los Angeles and Long Beach harbors, is midway between San Pedro and Long Beach (Fig. 1). Production was first developed in January, 1932, from the Repetto (Lower Pliocene) formation.

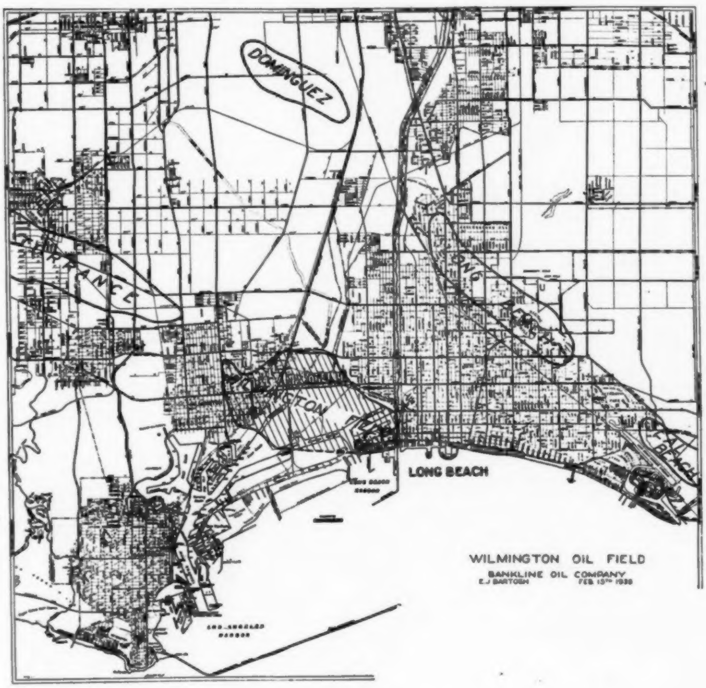


FIG. 1.—Map showing location of Wilmington oil field in relation to Torrance, Dominguez, and Long Beach.

Topography of the area is even, with low flat terraces which were cut by the Los Angeles River, now confined to a flood channel. The elevations range from 10 to 40 feet with very little evidence of subsurface structure except in the slight elevation of land surface in the

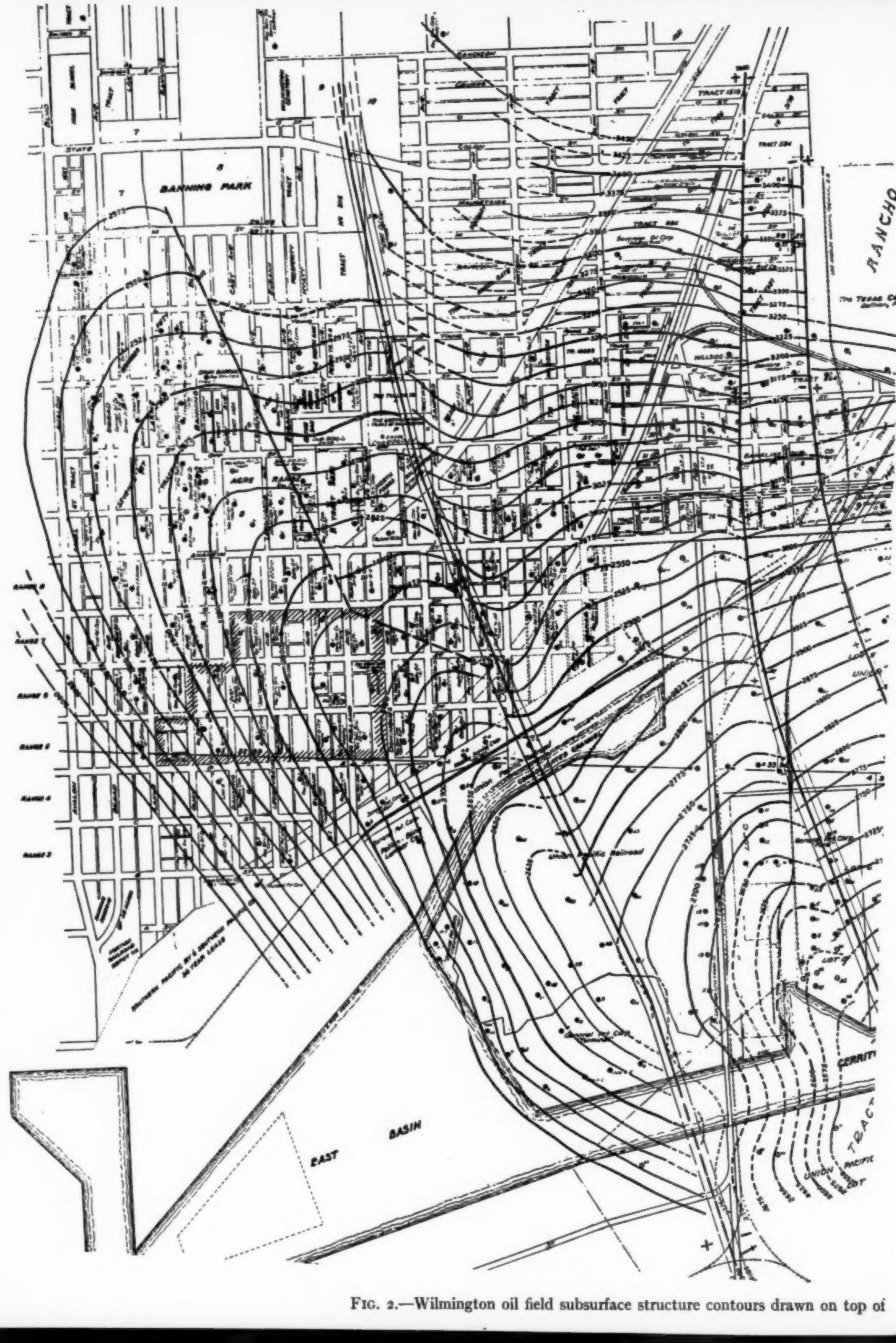


FIG. 2.—Wilmington oil field subsurface structure contours drawn on top of

Ranger zone (February 15, 1938). Contour interval, 25 feet. Datum, sea-level.

City of Long Beach east of the Los Angeles County Flood Control Channel.

HISTORY OF DEVELOPMENT

As early as 1925, or during the close of the development of Torrance oil field, several wells were drilled in the Main Street area in an effort to find possible extensions of the Torrance field. Most of these wells were definitely edge wells and low structurally with regard to both Torrance and Wilmington. From 1925 to 1932 a few wells were drilled southeast of the Main Street area, and on January 26, 1932, the Ranger Petroleum Company's Watson No. 2 was completed at a depth of 3,786 feet with an initial production of 75 barrels daily, 13° A.P.I. gravity, from the Repetto (Lower Pliocene) formation, thereby discovering the Ranger zone. Subsequent drilling in 1935 and 1936 by various operators proved better production southeast of the original well, which is now the extreme outpost well, being located on the northwest plunge and north flank of the developed structure.

The discovery of the Tar and Terminal zones may be attributed directly to a structural interpretation of the area, in which a seismograph may have played an important part. Subsurface correlation work on the early outpost wells may be credited for the discovery and later development of the Ranger zone.

In May, 1935, considerable interest was aroused in that part which is now called the west area of the field, shown on the structural map as the shaded area. Gasoline was found in a cesspool being dug, at a depth of 15 feet. About 150 holes were bored in the east part of the area and yielded small amounts of brownish oil of 50°-59.5° A.P.I. gravity, and a practically clear product. The depths of these holes ranged from 15 to 30 feet although most of the oil was coming from the upper sand at 15–17 feet, probably deposits of Recent age. Analysis of this oil placed the product in the distillation range of gasoline; another classed a sample as cracked distillate, and a third tested 3 per cent natural gasoline, 2.5 per cent kerosene, the balance gasoline. Sulphur content was reported as 0.15 per cent.

The general opinion was that the source of this production was from leaky pipe lines traversing the area, for soon after repairs or new lines were laid production declined rapidly and operations were practically terminated. The various state and city regulations which were being enforced against fire hazards, well-permit fees, bonds, *et cetera*, to be posted, precluded further activities in the district.

The area came into prominence as a major oil field of southern California on December 6, 1936, when the General Petroleum Cor-

poration of California completed Terminal well No. 1 at a depth of 3,625 feet with a daily production of 1,500 barrels, 20° A.P.I. gravity, from a 600-foot Upper Miocene section, thereby establishing discovery of the Terminal zone. In the drilling of this well two stratigraphically higher productive sands were tested showing heavy oil and one lower member, later called the Ford zone, yielding a small amount of 27°-30° oil.

After the discovery of the Terminal zone a drilling campaign began in December, 1936, and reached a boom period during the spring of 1937 when large operators began offset drilling along with the independent companies, developing holdings in the west and northwest subdivided areas. By June 1, 1937, 108 wells had been completed for a potential output of 65,985 barrels per day. Curtailment became effective on June 2, in the central part of the field and production averages for July, 1937, were 48,794 barrels daily from 180 wells (see production curve).

SUBSURFACE STRUCTURE

The subsurface structure of the field (Fig. 2) may be described as a regional anticlinal uplift forming an irregular-shaped dome with major pre-Upper Pliocene faulting transverse to the principal axial trend. The dip of the strata ranges from 2° to 15°. Magnetic[3] and drill-pipe orientation of cores from some of the older wells aided materially in determining subsurface structural trend, and since the field has developed the results of these early core orientations have been confirmed.

GEOLOGY

The Quaternary formations are composed of alluvium and terraces underlain by sands, clays, and gravels varying in thickness from 500 to 700 feet, lying unconformably on the Pico (Upper Pliocene) formation. This is shown graphically on the columnar chart (Fig. 3). In some wells on the north flank of the field large fossil deposits are found in the upper 200 feet of the Pleistocene and in one well on the Dominguez Harbor Tract a charred redwood log deposit was noted at a depth of 287–293 feet. Similar deposits have been reported in other near-by areas at approximately the same depth.

The interpretation of electrical logs indicates that the Pleistocene beds contain fresh water. This has been confirmed by certain wells north of Anaheim Boulevard which have flowed approximately 300 barrels of very pure fresh water from a depth of 600–700 feet on failure of water shut-off on the surface casing.

[3] E. D. Lynton, "Laboratory Orientation of Cores by Their Magnetic Polarity," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 21, No. 5 (May, 1937).

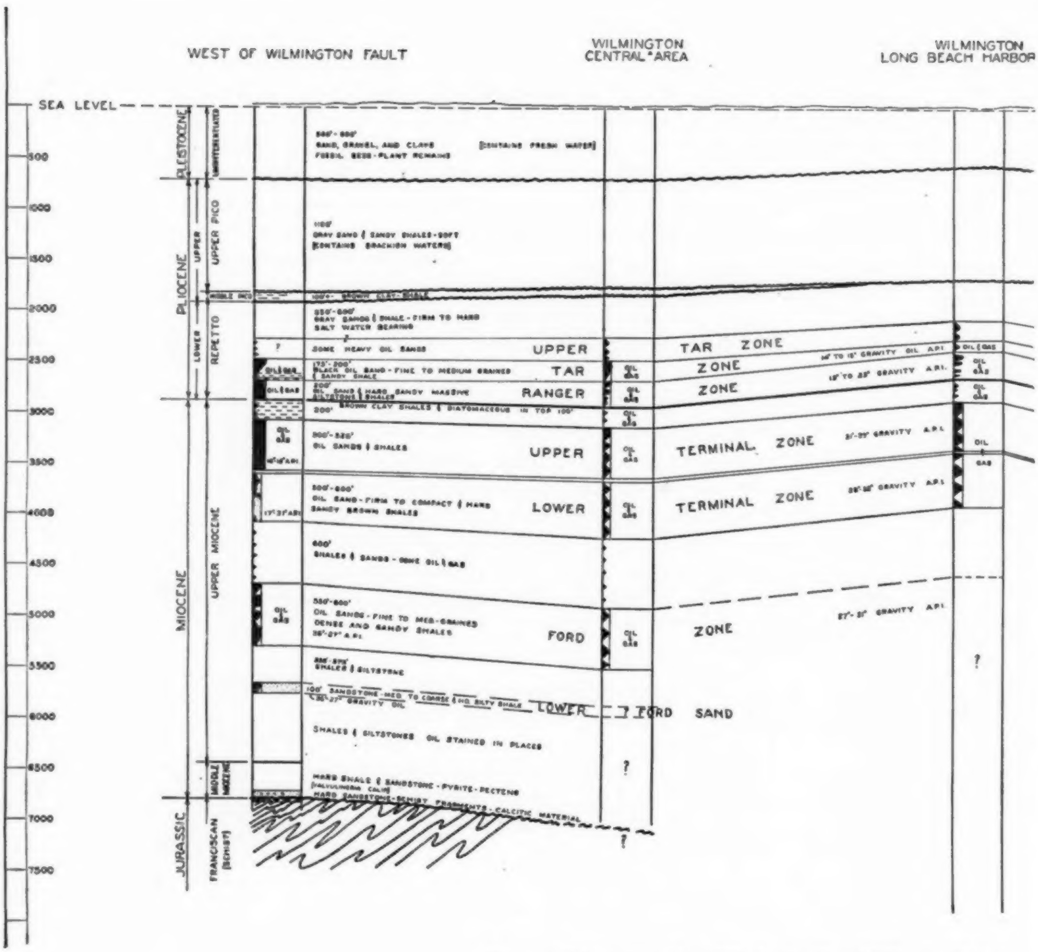
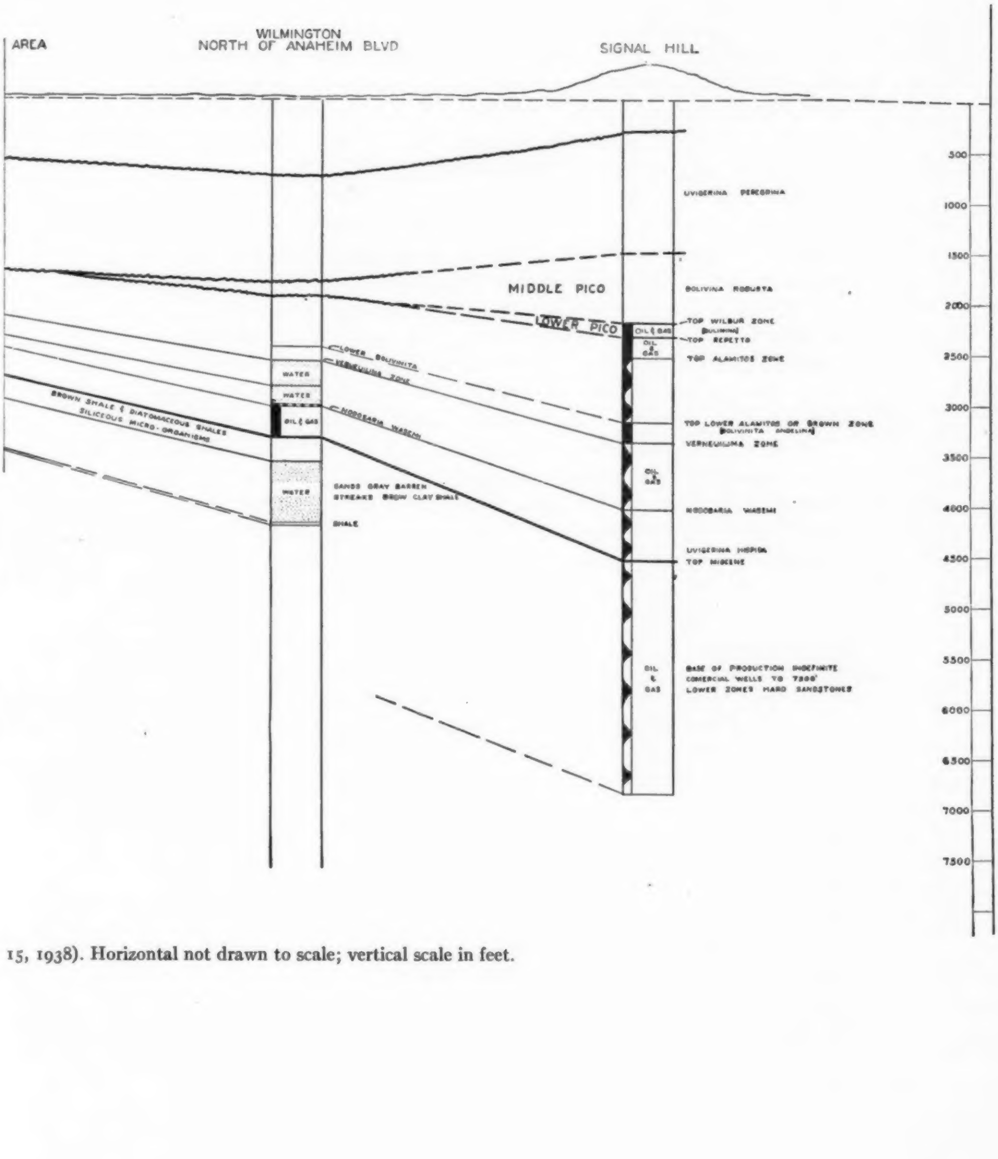


FIG. 3.—Columnar section, Wilmington-Signal Hill area (February

15, 1



15, 1938). Horizontal not drawn to scale; vertical scale in feet.

The upper part of the Pico formation (Upper Pliocene) rests unconformably on the Repetto formation (Lower Pliocene) in the Long Beach Harbor area where the highest part of the structure lies, whereas in the central and northwest part of the field the middle Pico is overlapped by the upper Pico, leaving a disconformity between the upper Pico and middle Pico brown shales and an unconformity between the middle Pico and Repetto. These discordances are very noticeable in all cross sections and show the lensing of sand members toward the high areas and thickening of formation basinward.

The upper Pico beds all appear to contain brackish water which may be due to the impervious middle Pico members excluding any upward migration of the more saline waters known to exist in the underlying sands of the Repetto formation.

The Repetto (Lower Pliocene) is 1,000 feet thick and consists of alternate beds of firm to hard sands and shales containing many concretions. The top of the formation is reached at approximately 1,675 feet in the Long Beach Harbor area or the highest structural part and extends to a depth of 2,620 feet, or to the top of the Miocene. The thinning of the Repetto section is practically entirely due to decrease in the amount of sand as most of the shale members are very consistent throughout the area. The upper part of the Repetto has probably been eroded to some extent although faunal sequence is lacking to prove the exact amount of section missing. The Repetto and upper Puente (Upper Miocene) contact is normal. In the Signal Hill or Long Beach oil field the entire Pliocene section is represented and is considerably thicker compared with the Wilmington section. The generalized columnar section shows the position of formations and zones producing oil and gas relative to the type section of Signal Hill taken at approximately the top of the structure.

In the Wilmington field the upper 100 feet of the Miocene is marked by a predominance of brown shales containing *Uvigerina hootsi* Rankin and gray-white diatomaceous shales with thin partings of oil sand. Underlying this diatomaceous member is 100 feet of platy and brown dense massive shales commonly referred to locally as "poker chip shale." The upper 200 feet of Miocene contains many siliceous micro-organisms. This is referred to as an intermediate section.

The 1,100 feet of Miocene section from 2,800 to 3,900 feet in the Long Beach Harbor area consists chiefly of well sorted fine- to medium-grained sands with intervening members of brown clay shales in the upper 500 feet, whereas the lower 500–600 feet of section consists of firm to hard sands and alternate layers of sandy massive shales with irregular inclusions of fine to coarse sand and siltstone.

Many hard calcareous or porcelaneous shales are found in the Miocene. The entire upper section is fairly uniform from the contact with the Pliocene down to the Middle Miocene formation, the top of which is at 6,425 feet in the western fault block. The middle member consists of sandstone, gray-brown calcareous shales with pyrite and pyritized pectens and extends down to the top of the Franciscan schist (Jurassic?) which has been found at 6,787 feet. *Valvulineria californica* occurs in this section and is very plentiful from 6,673 feet to 6,680 feet; also calcitic material is found in the lower 50 feet.

FAULTING

There are six normal faults outlined by the present development and one minor reverse fault indicated (E.-W. section, Fig. 4).

1. In the extreme west part of the field a minor normal fault exists with a vertical throw of 25 feet at the Ranger zone to 40 feet at the Miocene contact. It hades 22° easterly as computed at the Miocene contact and has a N. 26°–70° W. strike. Production is affected only locally by this fault with the better wells on the west or upthrown side of the fault.

2. The first major normal fault is called the Wilmington fault. It has a throw varying from 195 feet at the Ranger zone to 265 feet at the Miocene contact. The average hade north of Anaheim Boulevard is 32° easterly and strikes N. 14°–22° W., measured along the fault plane; the hade increases to 36° in the area south of Anaheim Boulevard or the central area.

3–4. Graben faults. The two parallel faults of less magnitude with the same general trend cut through the central part of the field east of Ford Avenue. They are referred to as the graben faults although the graben is evident only north of Anaheim Boulevard. The west fault, known as the Ford fault, strikes N. 1°–23° W., has a hade of 20° easterly in the area north of Anaheim Boulevard and 34° easterly in the south-central area, or an average hade of 27° with a throw of 45 feet at the Ranger zone to 125 feet at the Miocene contact, the greater throw and displacement being at the highest part of the structure. The east fault forming the graben striking N. 4°–24° W. has a hade of 20° east with a throw of 40 feet. South of Anaheim Boulevard this fault becomes normal and is downthrown on the east and upthrown on the west, but has very little displacement, possibly 25–30 feet. The location is not very definite because few wells have been drilled into the fault zone in the older beds. Correlating some of these faults is very difficult in some of the Pliocene horizons unless wells are cored through the brecciated zones or encounter good marker beds at the

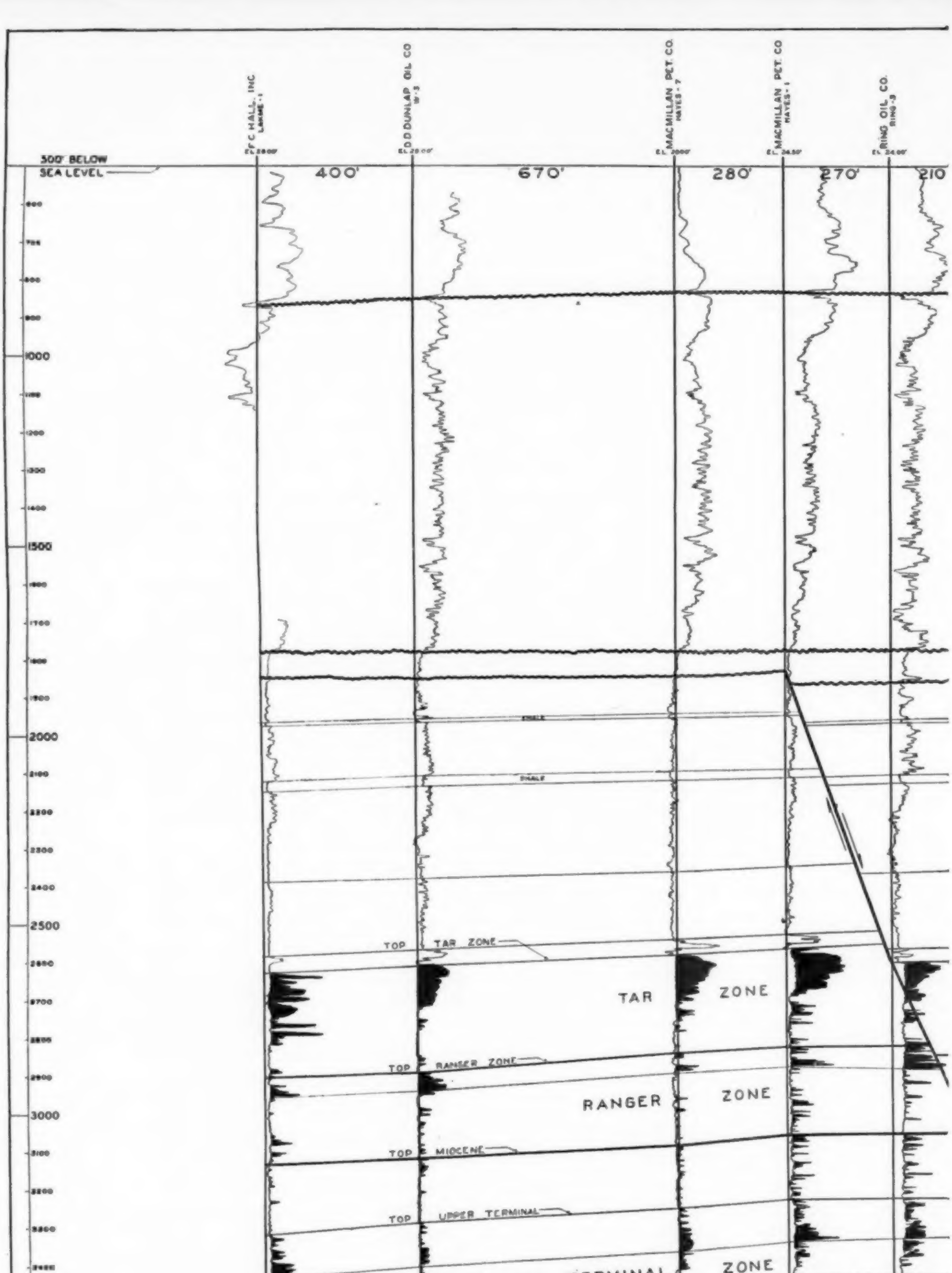
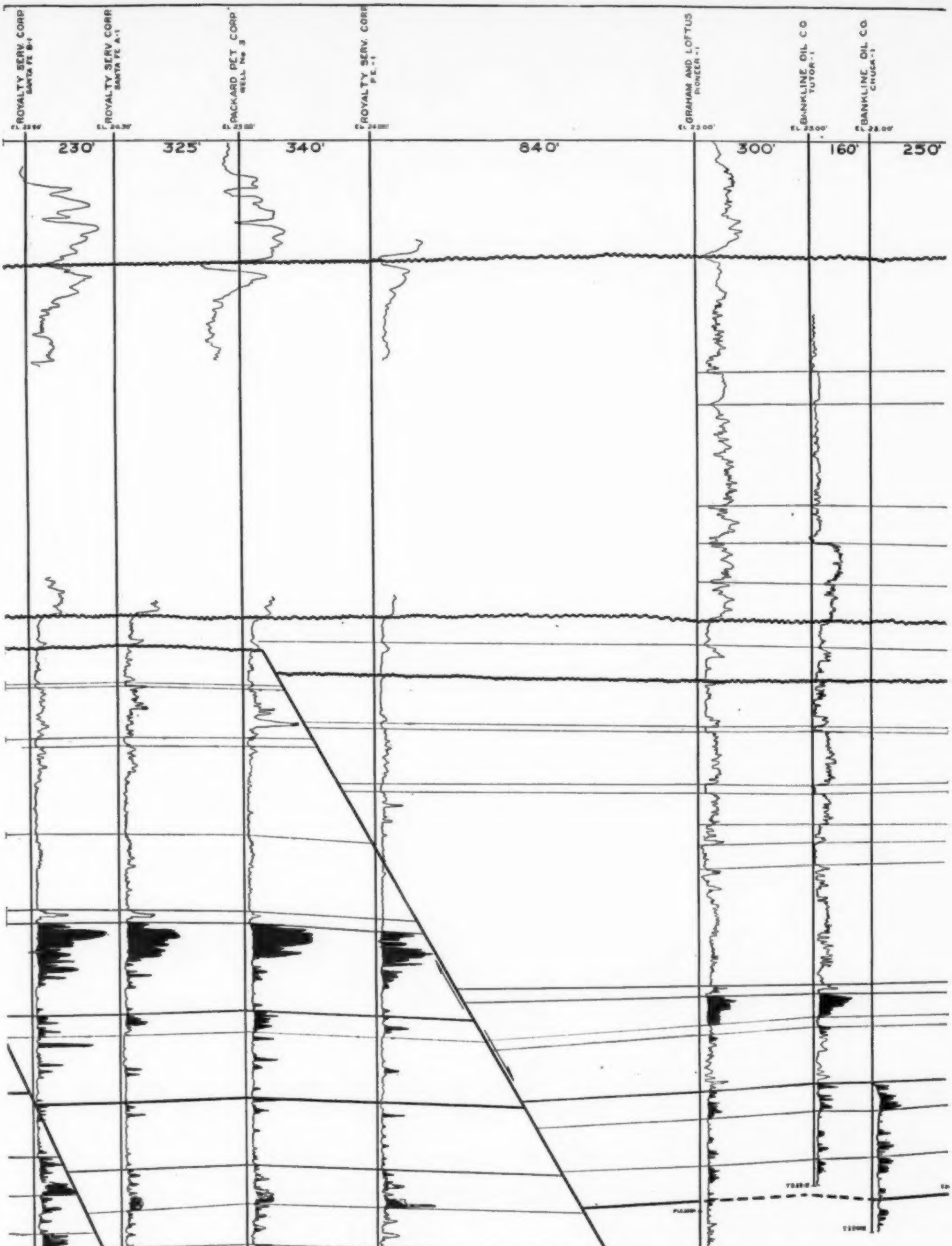


FIG. 4.—East-west cross section, north of Anaheim Boulevard,



Wilmington oil field. Horizontal and vertical scale the same, shown in feet.

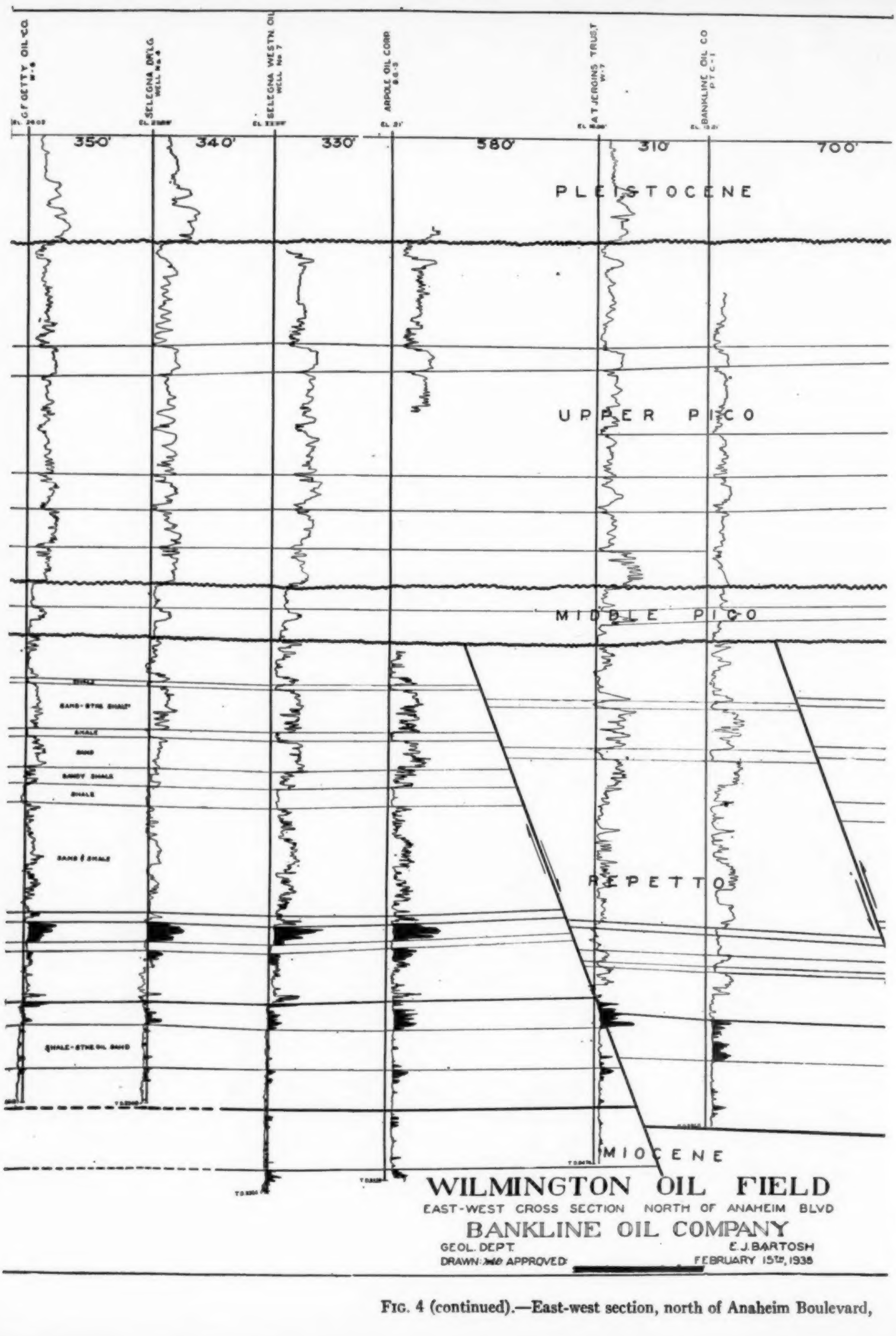
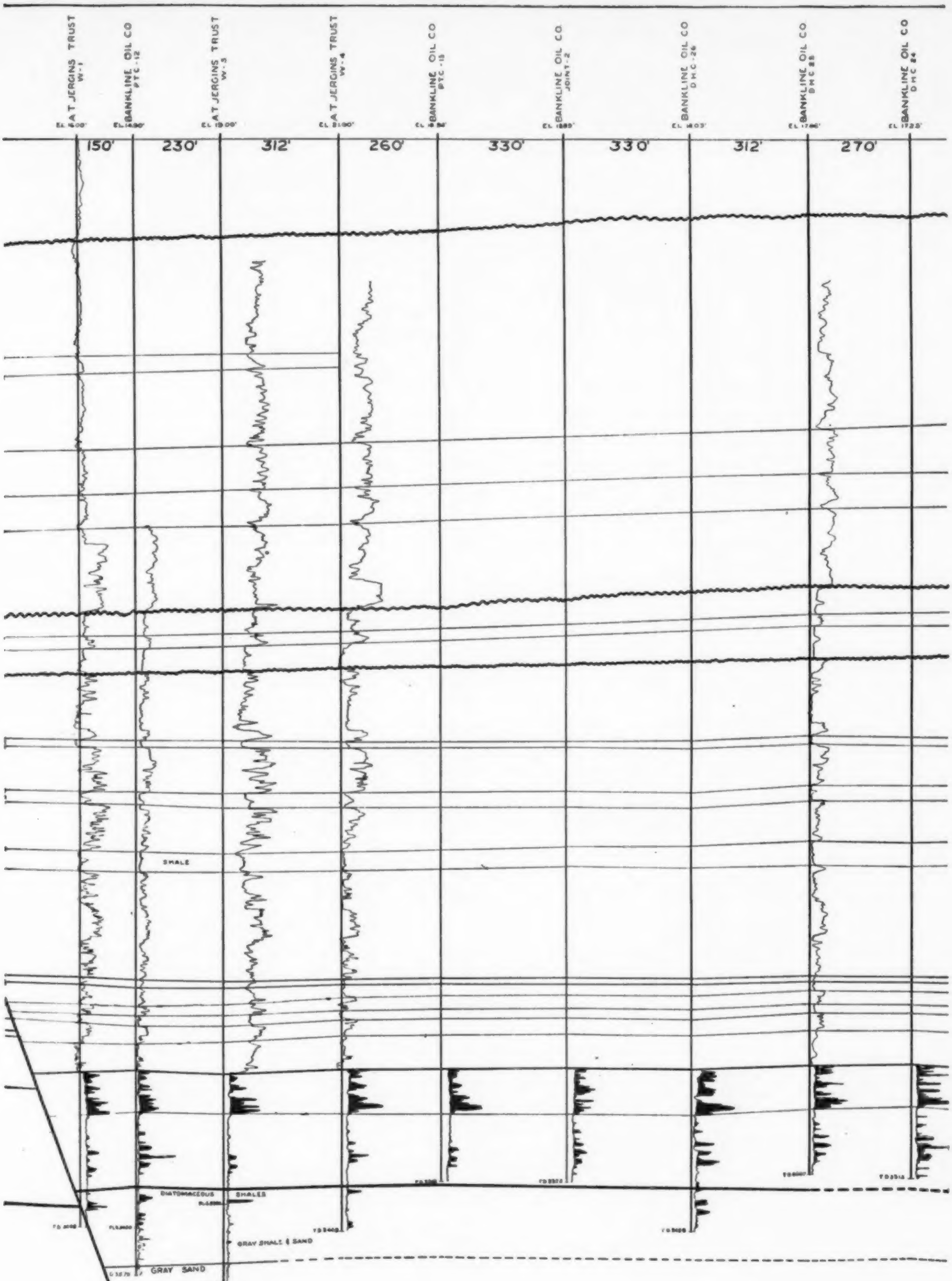


FIG. 4 (continued).—East-west section, north of Anaheim Boulevard,



Wilmington oil field. Horizontal and vertical scale the same, shown in feet.

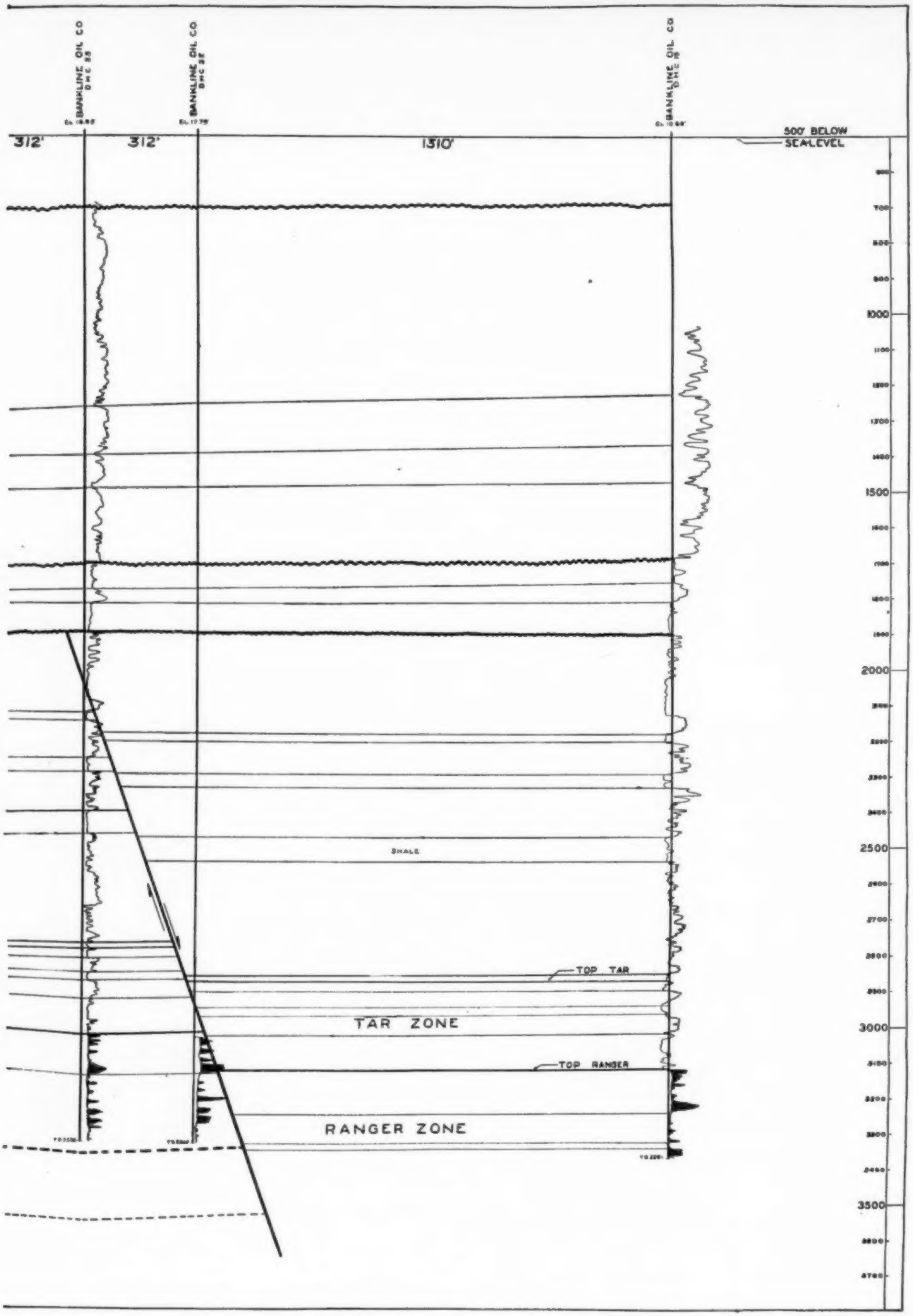


FIG. 4 (concluded).—East-west section, north of Anaheim Boulevard.

point of shearing. This graben immediately north of Anaheim Boulevard is somewhat suggestive of horizontal movement caused by compression and folding of the underlying Miocene formation at the hinge of this fault. The cored Miocene formations in this area are all sharply folded and distorted, whereas a short distance from the fault the apparent dip of the beds is normal.

5. The fifth fault referred to as the Dominguez Harbor fault with beds upthrown on the west and downthrown on the east strikes N. 29° W. and hades 15°–19° E. The vertical throw is approximately 110 feet, the exact figure not being definite due to few points of control. Additional wells will be drilled in this block which is highly productive and definite information on this fault will be obtained.

6. The most important fault (Fig. 5), from an economic viewpoint, is the Long Beach Harbor fault discovered by the development in the Long Beach Harbor area. This fault, also normal, has an average hade of 35° E. and a downthrow toward the east ranging from 85 feet at the Ranger zone to 100 feet at the Miocene contact; the strike is due north to N. 5° W. The entire upper 2,800 feet of Miocene section is barren of oil or gas east of this fault, only the Ranger zone being productive.

The major faulting apparently began near the close of Miocene time and continued progressively throughout the Lower Pliocene as determined from the detailed study of electrical logs and cored sections. The Miocene stratigraphy appears nearly uniform, whereas the Lower Pliocene stratigraphy varies according to different fault blocks. The sections of both basal Pliocene and Upper Miocene show many more sands and shales in the entire eastern part of the field, or the area east of the Long Beach Harbor fault.

A normal section uninterrupted by faulting is shown (Fig. 6), in the central areas and north flank. The overlying Pliocene, normal at the Miocene contact, shows considerable thickening of shales in the lower or depressed areas and gradational increase in sands and silts on the high part of the tilted fault blocks. There is also a progressive thickening of the sands toward the north, and at certain structural levels, considerable thickening of section, this together with a large amount of carbonaceous material and also shallow-water molluscan forms indicates a marine egression and regression during the period of deposition, possibly due to the progressive uplift of the region southwest of the area toward the Palos Verdes Hills.

OIL AND GAS ZONES

There are five producing zones.

1. Tar zone.—The Tar zone (Repetto, Lower Pliocene), the upper-

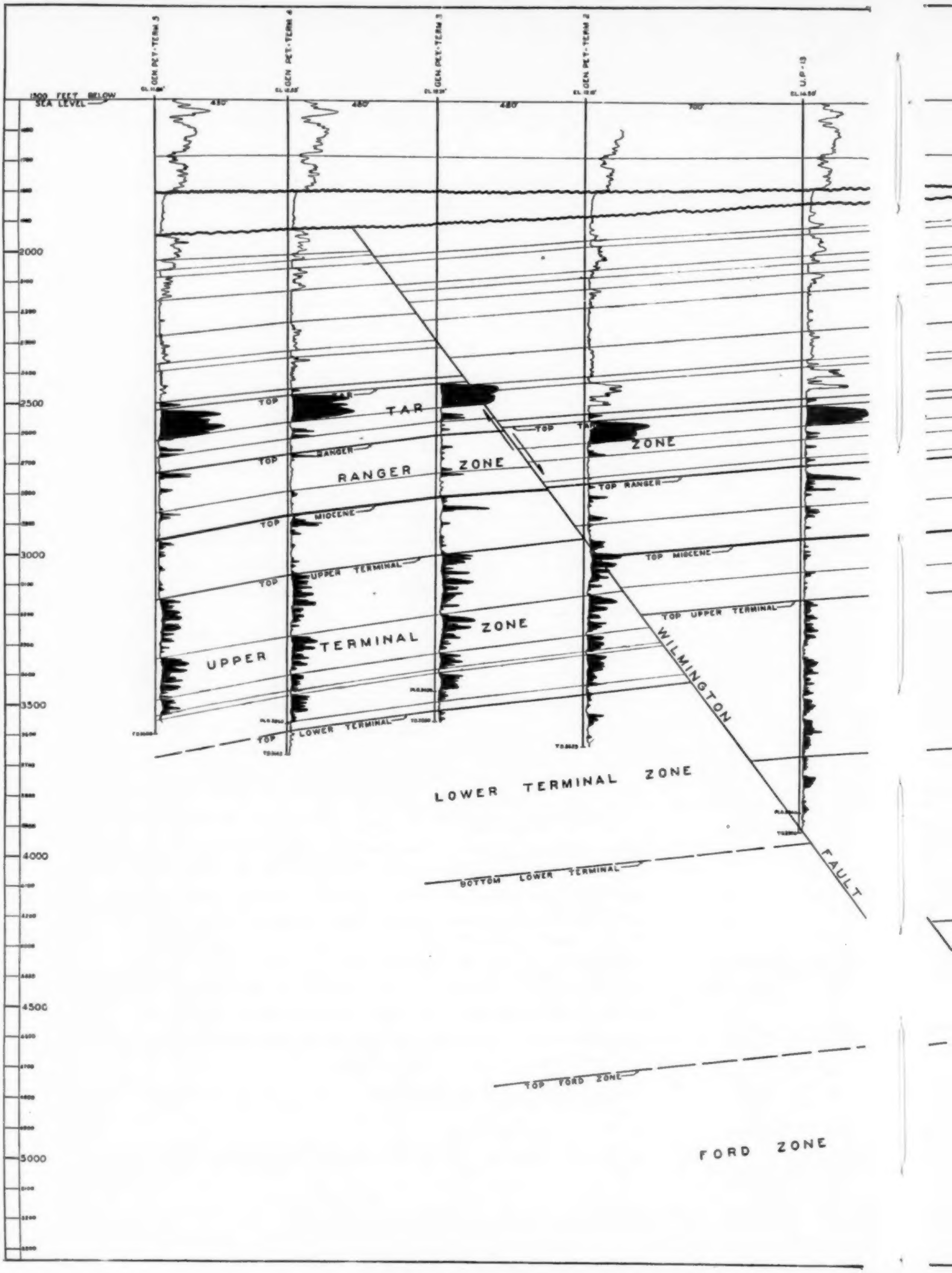
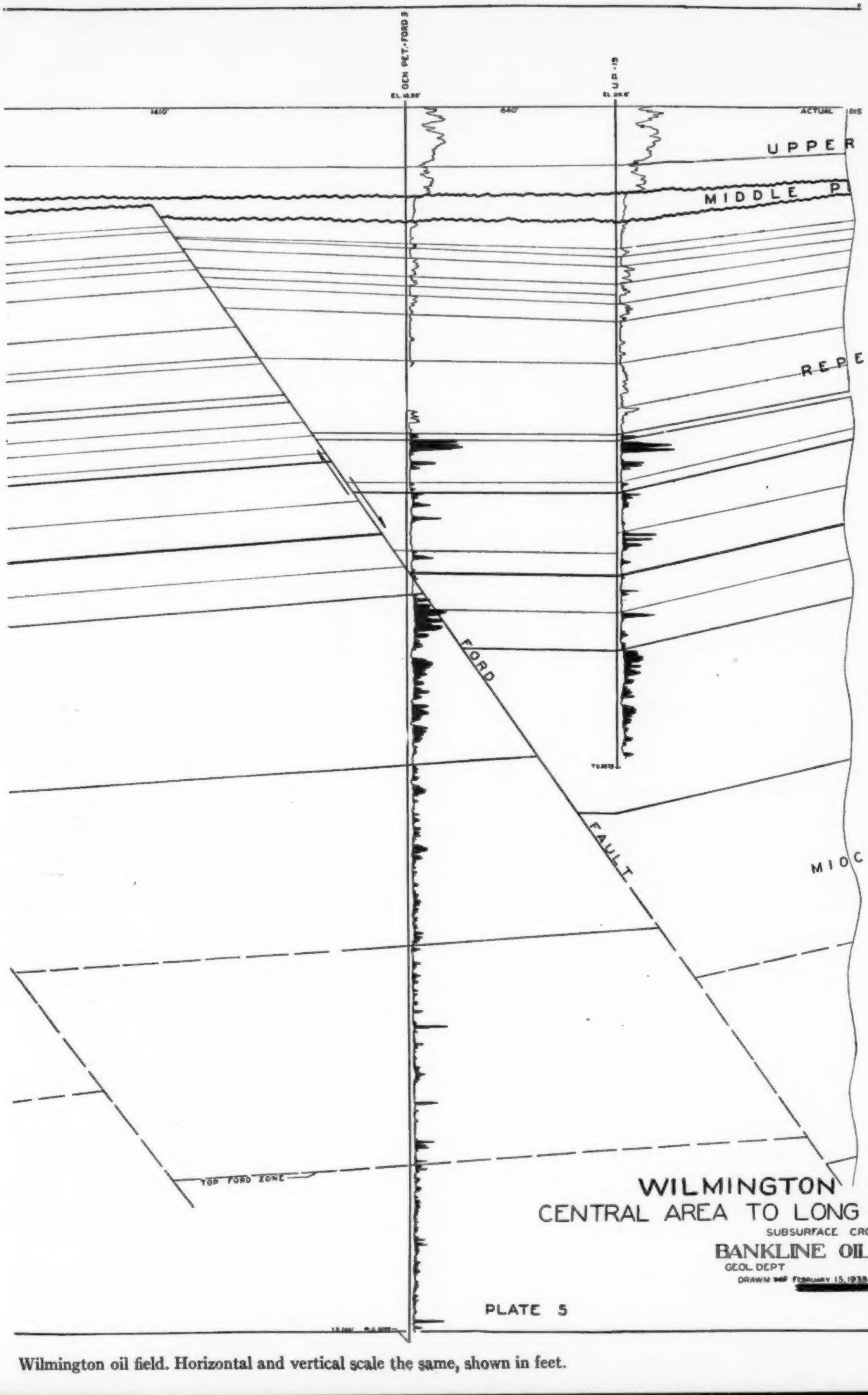


FIG. 5.—Subsurface section, central area to Long Beach Harbor area, Wi



Wilmington oil field. Horizontal and vertical scale the same, shown in feet.

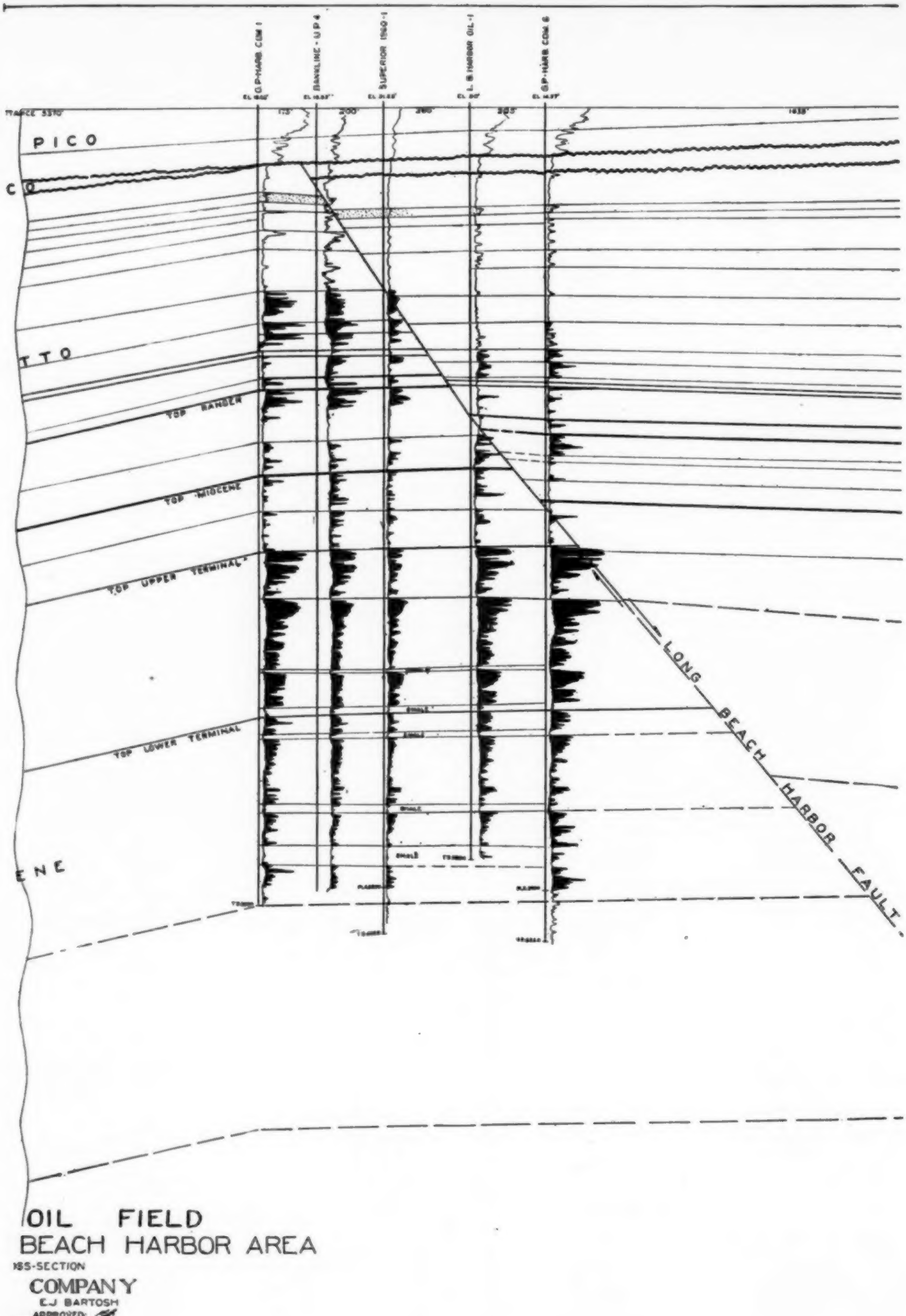
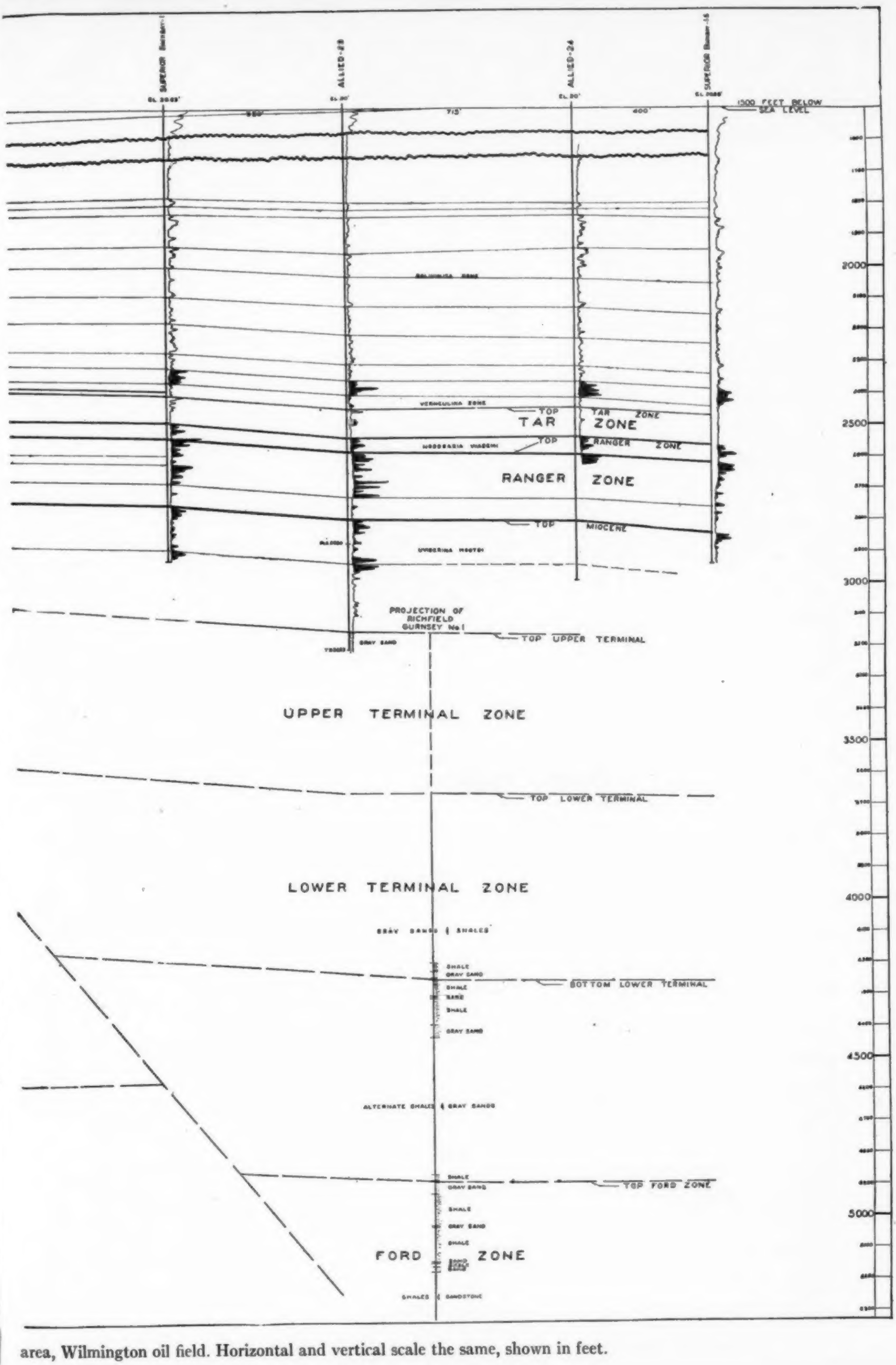


FIG. 5 (continued).—Subsurface section, central area to Long Beach Harbor

area,



area, Wilmington oil field. Horizontal and vertical scale the same, shown in feet.

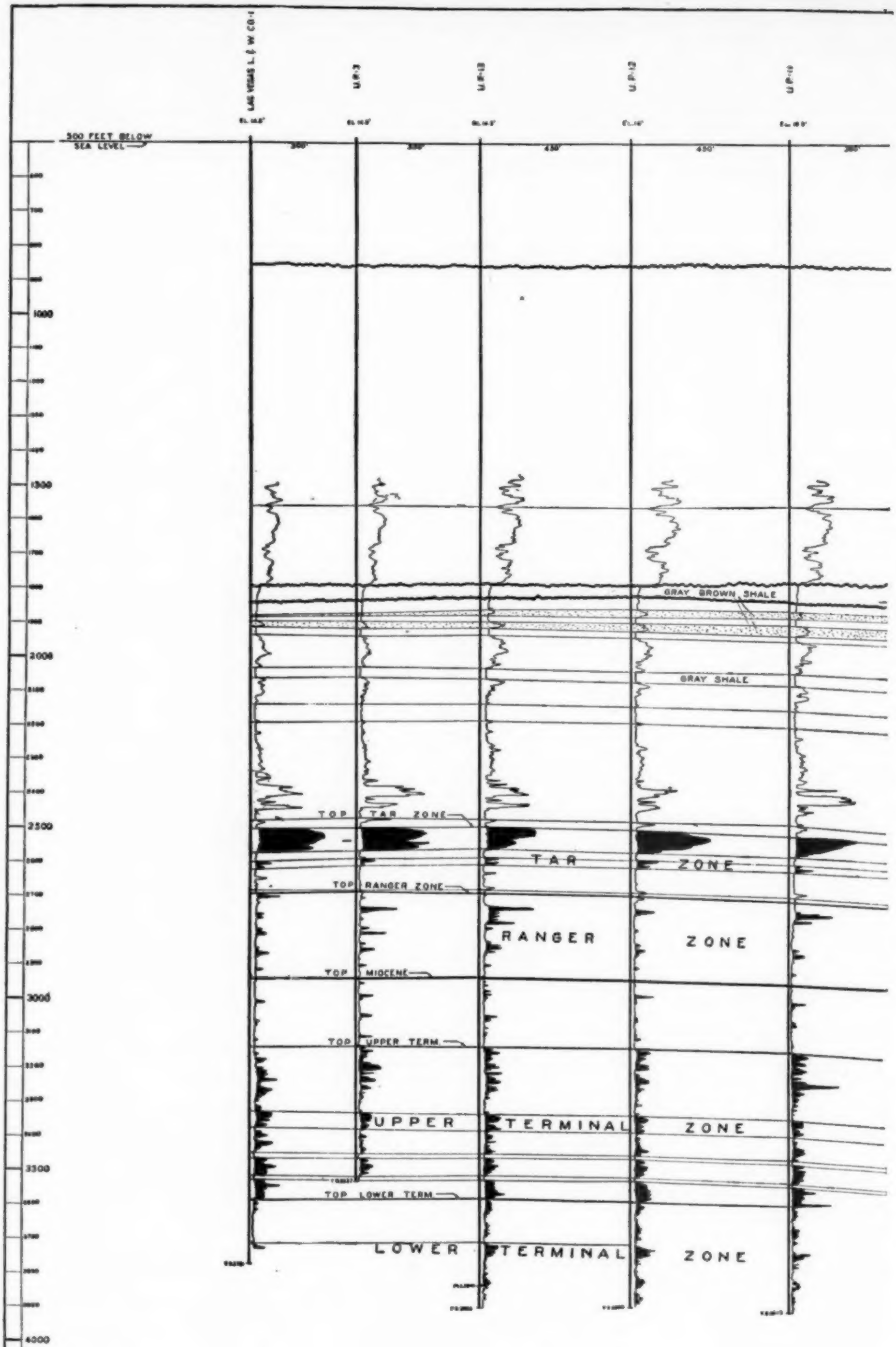
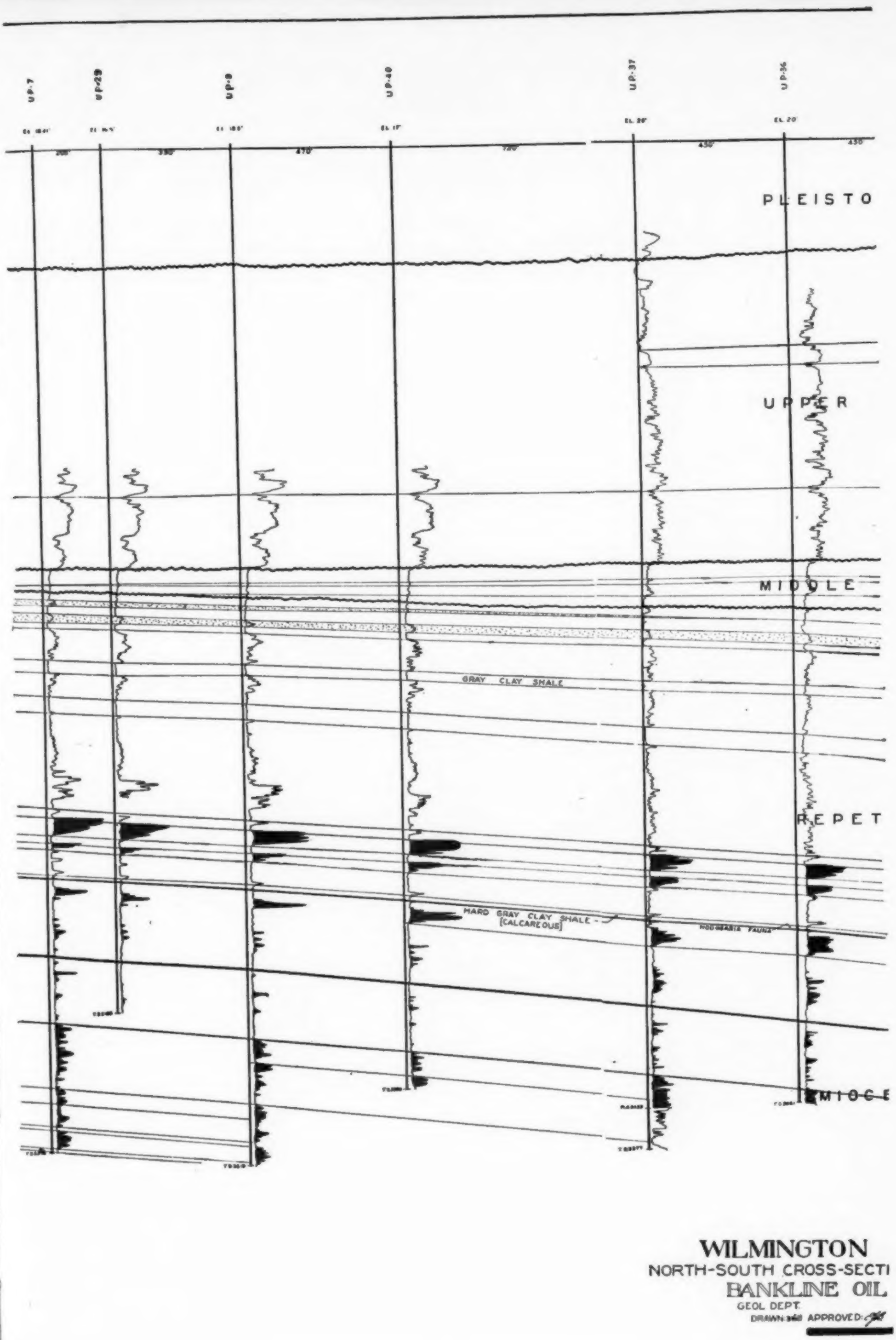


FIG. 6.—North-south section along Ford Avenue, Wilmington

on



oil field. Horizontal and vertical scale the same, shown in feet.

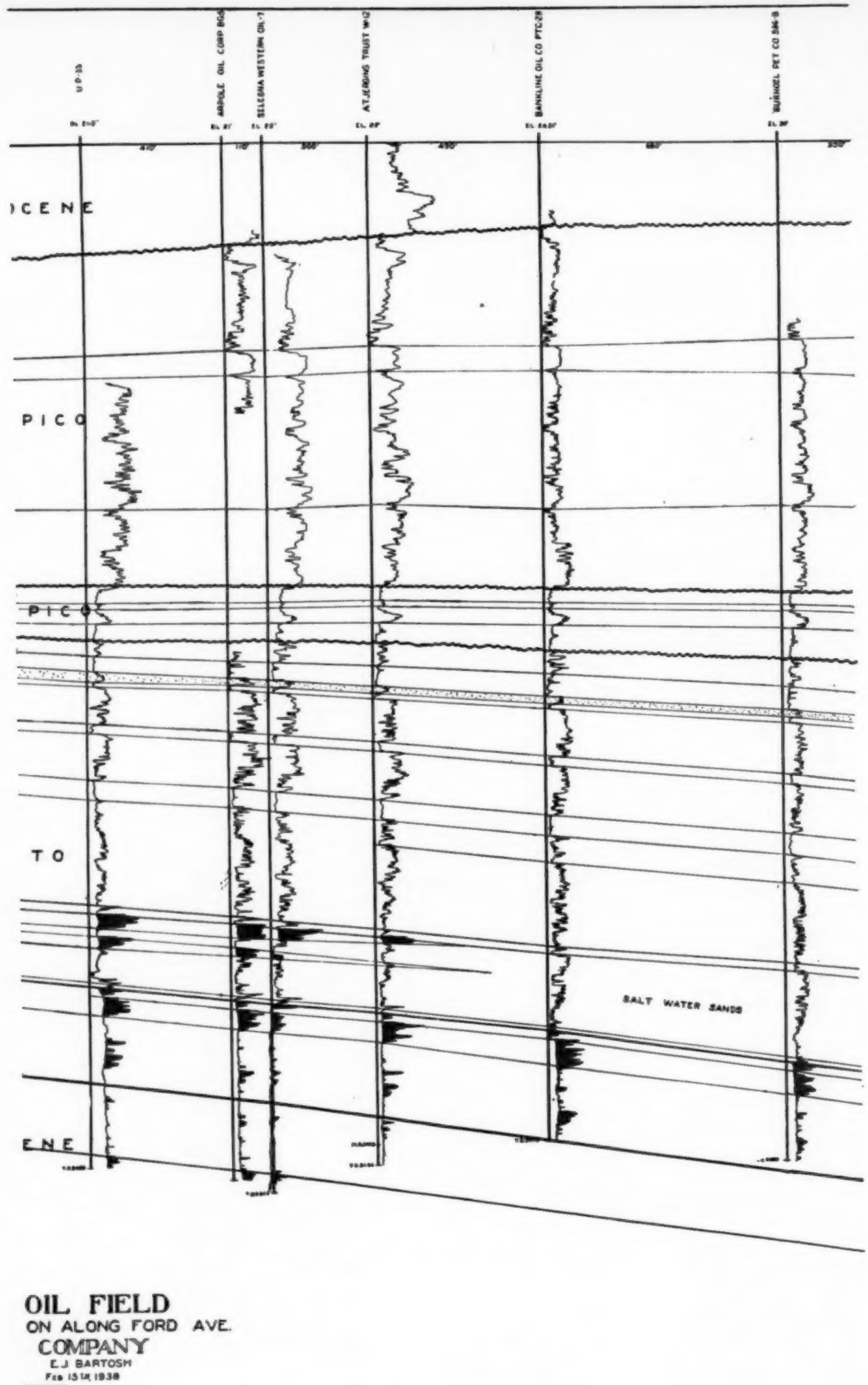
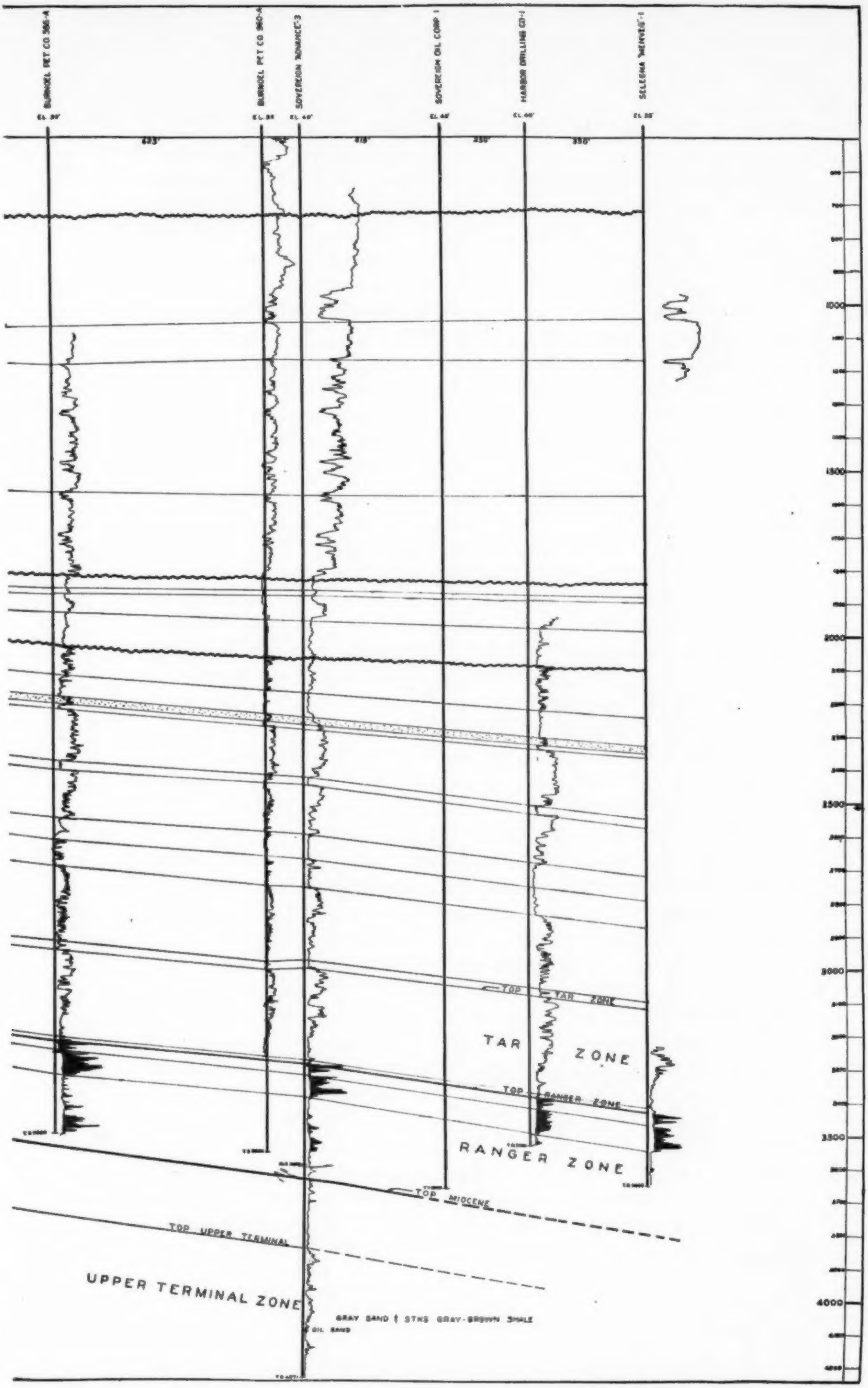


FIG. 6 (continued).—North-south section along Ford Avenue, Wilmington

on



oil field. Horizontal and vertical scale the same, shown in feet.

most productive zone, ranges in depth from 2,250 feet to 2,800 feet in the Long Beach Harbor area and has a thickness of 100–300 feet. The zone consists of very micaceous silts and sandy shales at the top grading downward to fine and coarse oil sands and firm sandy shales. The oil sands comprise about 33 per cent of the whole zone. The initial production of wells ranges from 195 to 325 barrels per day of oil varying from 12.5° to 15° A.P.I. gravity, with a gasoline content of zero to 3.73 per cent and a sulphur content of 1.94 to 2.43 per cent.

2. *Ranger zone.*—The Ranger zone (Repetto, Lower Pliocene) is encountered at depths of 2,370–3,500 feet with a thickness of 260–340 feet. This zone, which consists of 20–35 per cent oil sand, is marked by firm clayey shales at the top with calcareous concretions in places. It contains a plentiful, well preserved micro-fauna, including an important marker assemblage. The principal oil sands lie in the upper 200 feet and grade from medium- to coarse-grained oil sands to dense massive shales with several small lenses of fine silty oil sands in the lower 150 feet of the zone. A maximum of 130 feet of oil sand has been measured at the 3,150-foot subsurface contour. Oil from the zone ranges from 14.4° to 23.4° A.P.I. gravity and initial production rates vary from 50–3,000 barrels per day dependent on the structural position of wells. The gasoline content ranges from 3.0 to 21.0 per cent, and the sulphur content from 1.22 to 2.20 per cent.

The Terminal zone in the Puente formation (Upper Miocene) is divided into two sub-zones—upper Terminal and lower Terminal zones. The top of productive sands from this zone lies 200 feet below the Miocene contact or at depths ranging from 2,837 to 3,450 feet.

The 200 feet of section above this zone, which the writer has previously referred to as an intermediate zone, consists of brown clay-shale and diatomaceous shales, together with several thin oil-sand members productive in limited areas. Normal penetration of a typical Ranger zone well on the north flank below the 3,000-foot subsea contour, indicates the top of the Miocene as the limit of the saturated or productive Ranger zone. No doubt, wells located structurally high could produce from the entire Lower Pliocene and Miocene zones together with success, but it is believed this practice is not advisable due to variations in formation pressures and gravity of oils.

3. *Upper Terminal zone.*—The productive thickness of the zone varies from 40 feet at the 3,450-foot level to 500 feet at the highest structural point. It consists of alternate fine- to medium-grained oil sands and brown platy laminated shales, approximately 65 per cent of the zone being oil sand. Tests of 300 feet of these sands have shown a porosity of about 25 per cent.

Initial production ranges from 300 to 4,000 barrels daily of 17.0°–25.0° A.P.I. gravity oil. All the lower-gravity oil is produced in the area west of the Wilmington fault. The sulphur content varies according to gravity from 1.34 to 2.5 per cent, the lighter oil having the less sulphur.

4. Lower Terminal zone.—The top of this zone is encountered at depths of 3,375–3,600 feet and probably extends structurally lower than this point but areal limits are not yet defined. The maximum productive thickness at the highest level is 530–600 feet. It consists of firm fine- to medium-grained oil sands and sandy shales with irregular inclusions of sand. The lithologic character of this zone is very different from that of the upper Terminal zone, primarily because of the density of sands and the presence of siliceous and calcareous sandstones and porcelaneous or cherty shales in considerable thickness. The zone consists of approximately 50 per cent oil sand, which together with the upper Terminal zone, gives an average total percentage for the whole zone of 57.5 per cent oil sand. Initial production from this zone varies from 2,500 to 4,000 barrels daily of 27°–30° A.P.I. gravity oil. A combined potential rate of one well in the Long Beach area developed 9,600 barrels and 4 million cubic feet of gas from the Ranger, upper Terminal, and lower Terminal zones, flowing from each zone independently of the others. Analysis of this oil shows a sulphur content of 0.89 per cent and gasoline content up to 34.0 per cent.

5. Ford zone.—The top of this zone, which has been developed in only a few wells, but prospected in the discovery well, is found at 4,800–4,850 feet and is 550–600 feet thick. It consists of very fine to coarse indurated oil sands, the coarser sands being permeable in places. Approximately 50 per cent of this zone is sand of which about half is barren because of its low porosity. The initial production ranges from 500 to 700 barrels of 27°–31° A.P.I. gravity oil. The crude contains 0.81 per cent sulphur and 30.97 per cent gasoline.

Another productive zone, the lower Ford, in addition to the foregoing zone, is encountered at depths of 5,450–5,675 feet. This zone, proved in the western part of the field only, is approximately 100 feet thick. Initial production of 200–400 barrels daily of 26°–29° A.P.I. gravity oil has been developed. In the extreme eastern fault block this zone is now being prospected and to date only a few showings have been found. The exact stratigraphic position of sands is not definitely known.

In addition to the Tar zone there is also a stratigraphically higher zone 185–200 feet thick which contains heavy oil-bearing sands in a

limited part of the field and up to the present time no attempt has been made to develop this production. Cored sections indicate a number of intervening barren or semi-barren sands which probably contain water. At some future date it may be profitable to produce this heavy oil.

In some parts of the field it is a common practice to produce from various zones together. This, of course, is done only where no intervening water is present. Some wells in the westerly area and the north-central flank that have not limited their penetration to a particular zone have developed some of these intervening waters. From the data available on titration analysis, waters of 1,640–2,120 grains per U. S. gallon of *NaCl* are produced from the lower Tar zone, the probable source being semi-barren sands found between the Tar and Ranger zones. Waters from the basal Ranger zone and the intermediate zone (uppermost Miocene) above the upper Terminal sand show a salinity of 1,300–1,950 grains per gallon. A sample from one well showed a chloride content of 19,137 parts per million and an iodide content (H.I.) of 148 parts per million. Upper Terminal zone sands on the north flank where edge-water encroachment occurs show a salinity of 1,650–2,080 grains per gallon. No attempt has been made here to show whether all these waters are closely related, as the range in *NaCl* is much the same. Detailed analyses may be of future benefit as more water problems develop.

The following table shows the number of wells producing from each zone as of March 2, 1938.

Zones	*Number of Wells* *Wilmington*	*Long Beach*	
Tar	7		
Tar and Ranger	25		
Tar, Ranger, and Terminal	3		
Ranger	120	15	
Ranger and upper Terminal	129		
Upper Terminal	74		
Lower Terminal	4		
Upper and lower Terminal	12	4	
Ford	6		
Ranger, upper Terminal, and lower Terminal		6	
	380	25	Total 405

Proved Area of Zones in Acres

Tar zone	1,750
Ranger zone	3,200
Upper Terminal zone	1,700
Lower Terminal zone	1,000
Ford zone	500

Drilling is done entirely by the rotary method and no unusual hazards have been encountered.

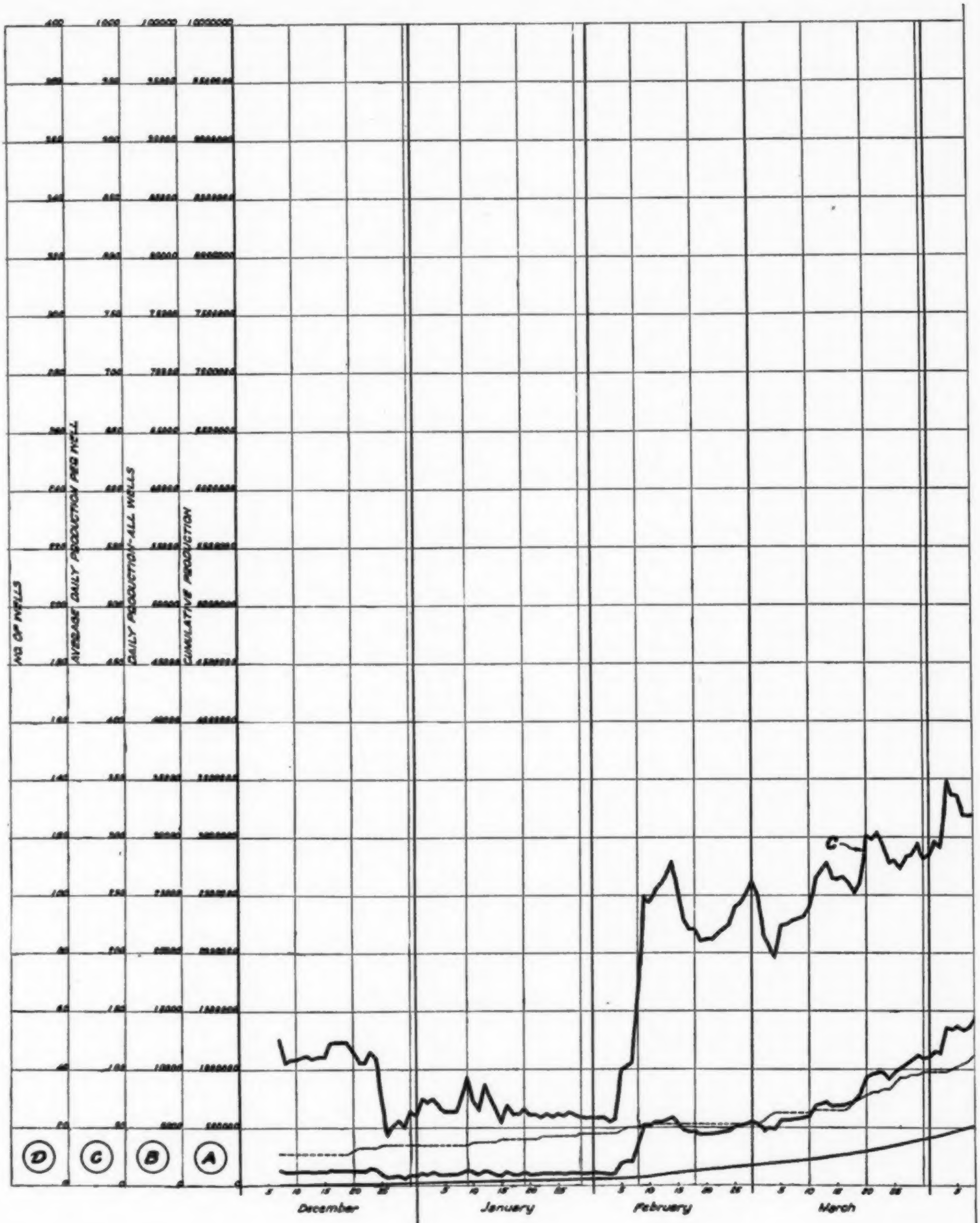


FIG. 7.—Curves showing production, in barrels, and number of wells in Wilmington oil field.

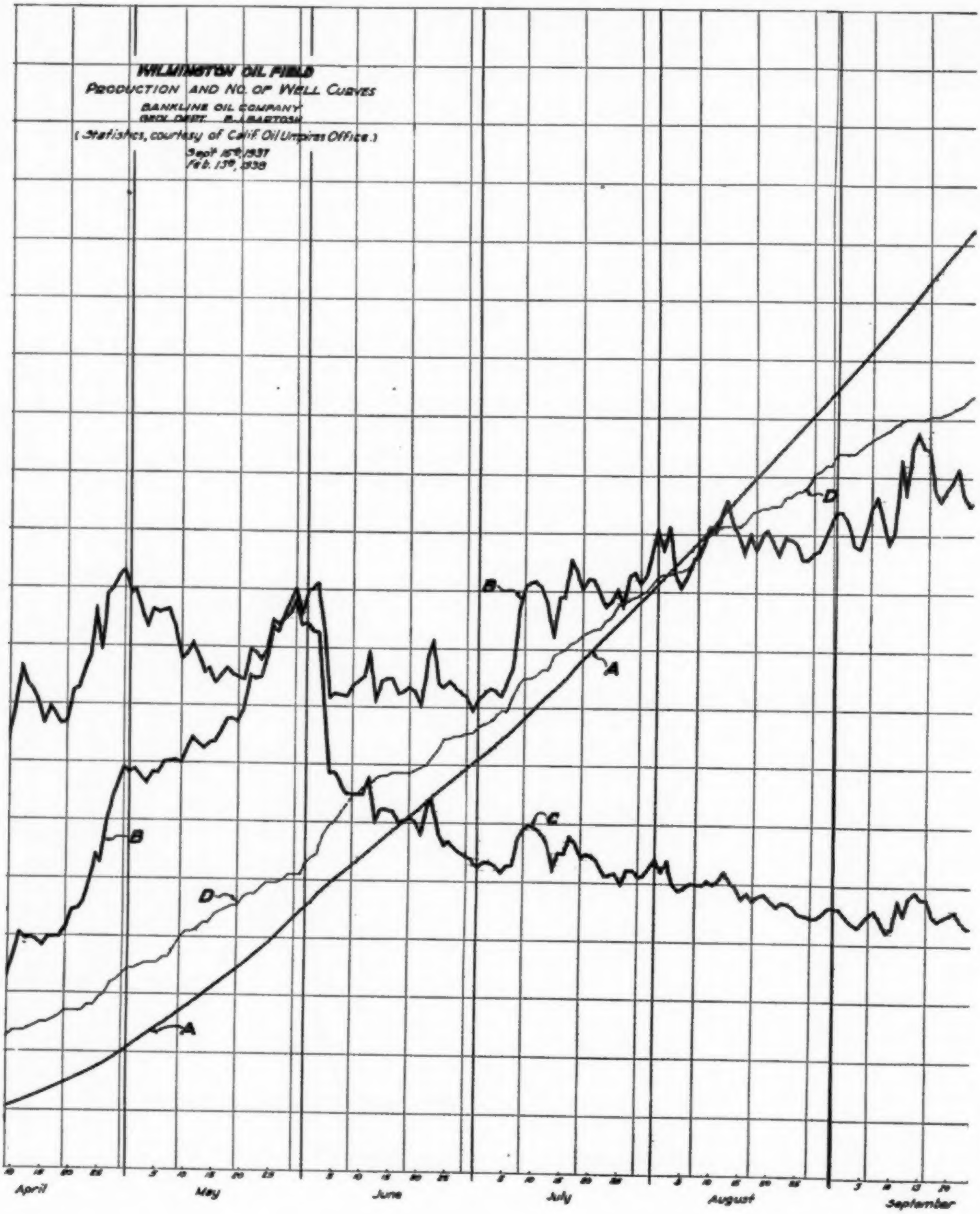
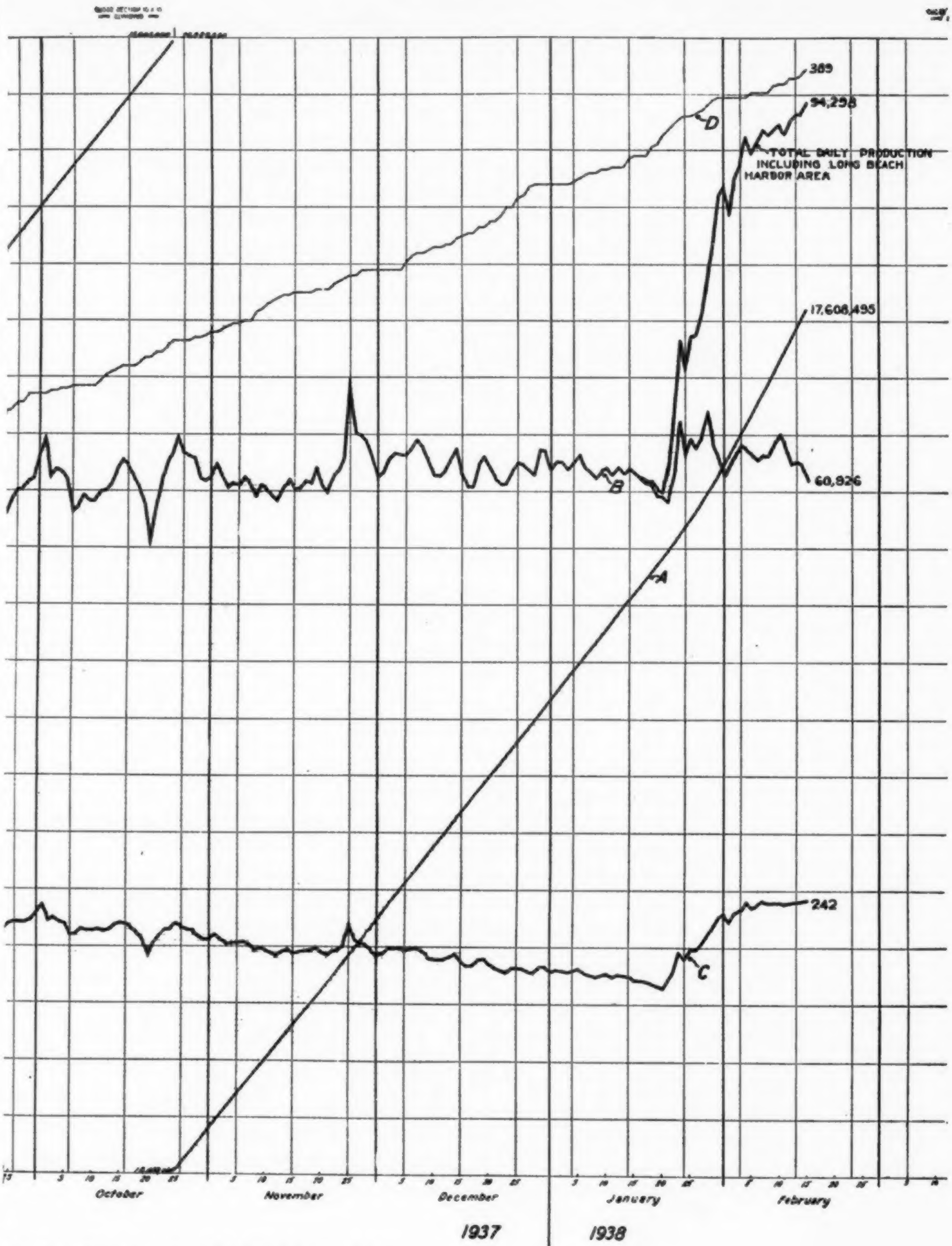


FIG. 7 (continued).—Curves showing production, in

barrel



barrels, and number of wells in Wilmington oil field.

Unlike some of the major fields in the Los Angeles Basin this field shows no high-pressure gas zones overlying the oil measures. Most of the flowing wells yield a very low volume of gas at first and as the rate of withdrawal increases the volume also increases. The Tar and Ranger zones show volumes of 50–550 thousand cubic feet per day and Miocene zone wells have developed volumes of 50 thousand to 4 million cubic feet. The gasoline content of the gas varies from 0.50 to 2.00 gallons per thousand cubic feet according to the pressure in the zones from which it is derived.

ANALYSES OF CRUDE OILS

RANGER ZONE

Gravity A.P.I. *18.4°* *Sulphur 1.69 Per Cent*

Per Cent Crude	
13.34	400 E.P. 49.3° gravity Gasoline 64 octane No.
2.50	Gas oil to 125 sec. residuum
84.16	Residuum 125 sec. vis. (14.6° A.P.I.)
100.00 Per Cent	

UPPER TERMINAL ZONE

Gravity A.P.I. *20.7°* *Sulphur 1.60 Per Cent*

Per Cent Crude	
16.11	400 E.P. gasoline of 66 octane No.
4.68	Gas oil to 125 sec. residuum
79.21	Residuum 125 sec. vis. (15.0° A.P.I.)
100.00 Per Cent	

PRODUCTION

Figure 7 shows the production curves as of February 15, 1938, for the entire field. These curves show graphically the rapid increase in the total number of wells and the sharp increase with the new production developed in the Long Beach Harbor area. Curve *A* shows the cumulative field production, which amounts to 17,608,495 barrels. Curve *B* shows the total daily production of 94,298 barrels. Curve *C* shows the daily average per well of 242 barrels. Curve *D* indicates the number of wells drilled, a total of 389.

On June 2, 1937, the average daily production per well was 463 barrels. Curtailment became effective on this date in the central area and along with the decline of the early wells, showed a drop in this daily average to 269 barrels by July 2, 1937. The average daily decline per well from June 4, 1937, to January 20, 1938, is 52.1 per cent exclusive of the Long Beach Harbor area. Completion of the first large well from the Terminal zone in the Long Beach Harbor area on January 21, 1938, and subsequent completions produced a steady rise in the field total and also in the daily average per well.

SUMMARY

As of March 2, 1938, there were 389 wells completed without a dry hole having been drilled in the field. The total proved area is about 3,200 acres. Potential production for the month of February, 1938, was 185,754 barrels daily and the latest, or March 2, actual production was 101,382 barrels daily from 374 active producing wells, having a daily average per well of 271 barrels. The production of large wells in the Long Beach Harbor area was curtailed voluntarily beginning March 1, 1938; the actual production for the entire field was 119,440 barrels on February 23 from 374 wells, or a daily average of 319 barrels. There are 37 active drilling wells in the field and considerable new production may be developed during the ensuing year as a large proved area remains to be drilled.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 1080-1087

RÔLE OF PETROLEUM GEOLOGIST IN DEVELOPMENT OF LAW OF OIL AND GAS[1]

GEORGE A. WILSON[2]
New Orleans, Louisiana

ABSTRACT

Legal concepts of mineral ownership and the nature of the property rights in oil and gas, including the theories of absolute ownership in place, qualified ownership, and so-called non-ownership, are discussed. Classification of the principal oil-producing states is made according to the theory of ownership prevailing in each.

The principal legal effects are attributable to different theories of ownership, including restrictions upon the creation and duration of estates in oil and gas separate from estates in the surface. The origin and operation of the lessee's obligation reasonably to develop the leased premises and to protect them from drainage are given. Circumstances are outlined under which the lessee's rights may be terminated, and the liability for trespass is discussed. The new theories of development are based on increased knowledge of geology, such as unitization and community operations. Expert testimony by the geologists on the administration of these phases of the law is important.

Oil and gas conservation programs have legal aspects which include both the substantive laws and their actual administration. Validity of restrictions upon production and drilling operations is largely dependent on their reasonableness in the light of geological information.

There are certain legal rights and obligations incident to geophysical prospecting, selection leases, liability for trespass, *et cetera*.

On first impression, it might seem that the rôles occupied by the petroleum geologists in the progress and development of the oil and gas business—which is now one of the largest and most important industries in the world—are entirely separated from the part played by the lawyers; that the geologists with their specialized knowledge and scientific instruments are the pioneers and forerunners whose sole concern is the discovery of new production for the lawyers and their clients to follow up and fight over! Actually, however, in many phases of the industry they must work together if the greatest benefits are to be realized by all the interests concerned—the producers, the landowners, and finally the public at large. In order to establish the verity of that assertion, a brief review must be made of the historical background and evolution of certain phases of the law relative to the ownership of oil and gas, and the legal rights and obligations of both landowners and producers, in order to show how the then prevailing geological information, or misinformation, as the case might have been, affected the development of the law from time to time.

CONCEPTS OF OWNERSHIP

So long as the capitalistic form of government is retained, and

[1] Read before the Association at New Orleans, March 16, 1938. Manuscript received, April 4, 1938.

[2] College of Law, Tulane University.

despite the efforts and dire predictions of certain groups of political theorists, it is probable that the present concept of ownership will withstand the current storm of radical attacks, and considerations of private ownership and concepts of individual property rights will be of first importance. Property is generally divided into the two broad classifications of "public" and "private," or things that belong to the State and things that are or may be owned by individuals. In certain foreign countries the ownership of all natural resources, including oil and gas, is vested in the government, so that all development is done only with the permission, and for the benefit, of the State. In the United States, however, from the very beginning we have recognized private ownership of minerals that underlie, or that may be produced from, privately owned land. The question is just what is the nature of that ownership. At the time oil and gas were first discovered and produced in commercial quantities in this country, and disputes arose as to the ownership of such production, the courts and lawyers were not adequately informed concerning the true nature of such commodities and the physical facts surrounding their production. It was believed generally that petroleum migrated freely from place to place and flowed about in streams or veins beneath the earth's surface. Obviously, the early courts concluded, such a moving stream could not be identified as a part of any one of the various individual estates under which it flowed, hence was not "owned" by the owners of the overlying land. In order to decide its ownership, the courts cast about for some guiding principle of already established law which might be applied to the new problem. They immediately seized upon the law applicable to wild animals, which, under already established rules of property, were regarded as fugitives and belonged, not to the man upon whose land they happen to be, but to the man who actually captured and reduced them to his possession, when, as, and if, such capture was effected. Therefore, said the courts, oil and gas in their natural state become the property of whosoever succeeds in actually obtaining physical possession by drilling and controlling the flow of the successful well. There followed, as a necessary corollary of that principle, the doctrine that any landowner became the owner of all the oil he could bring to the surface by means of wells drilled on his land, and, conversely, one lost all his right to oil that was drained from underneath his land by means of wells drilled on adjoining property. Of course, by this time we have learned from the geologists that petroleum does not flow freely about in underground streams, but, on the contrary, is tightly sealed in the open spaces of porous rocks which form a trap or reservoir, where it remains until a means

of escape is provided in the form of a well drilled through the overlying impervious rock. Nevertheless, the original conception of petroleum as a fugitive has been responsible for the formulation of certain legal principles which remain the law.

The development of the law was not uniform, however, in the several oil- and gas-producing states and there were evolved at least three principal theories of the legal nature of the landowner's property right in the oil and gas which might underlie his real estate. As a consequence of, and in accordance with, the particular ownership theory there recognized, the oil- and gas-producing states have been classified as "absolute," "qualified," and "non-ownership" jurisdictions. In the first type, that is, an *absolute-ownership* state, the best example of which is Texas, the law recognizes that the owner of the surface owns the minerals underneath, including oil and gas *in place*, just the same as solid minerals such as coal or iron. It follows as a consequence of this theory of ownership that the owner of a tract of land may sell subsurface portions of his land to others who thereby acquire a permanent estate in the land. Such division of ownership may take place between horizontal planes at varying depths, so that the subsurface ownership is divided into separate estates comparable to the layers of a layer-cake. Though ostensibly such a State recognizes ownership of the oil and gas *in situ* or in its natural undisturbed place, so that such ownership may itself be the subject of taxation, or be partitioned between co-owners in kind, nevertheless the fugitive character doctrine still applies to the extent that if the owner of adjoining land drills a well and drains some or all of the oil from underneath his neighbor's land, the total amount of oil thereby obtained becomes *his property* without any liability for payment to his neighbor for any part of such production.

The great majority of the oil- and gas-producing states adhere to what is known as the "qualified-ownership" theory. These states recognize that a landowner can not have an *absolute ownership* of oil and gas *in situ*, comparable to the ownership of solid minerals, for the reason that they may escape or be drained away by wells drilled on adjacent property. Such states do recognize, however, that a landowner has the *exclusive* right to use the surface of his land for the purpose of conducting appropriate exploratory and producing operations whereby the oil reservoir underneath may be tapped and its product reduced to possession—at which point the possessor becomes the actual *owner* of that production in the true sense of ownership. These states recognize the right of the landowner to sell to others this exclusive right to use the surface to drill for and produce oil and gas

from any reservoirs which may lie underneath the surface, so that the purchaser of this right may acquire a permanent mineral estate, or "real interest," in the land. This sort of interest also may be the subject of taxation separate from the balance of the land.

Finally, in the so-called "non-ownership" states, of which Louisiana is the best example, the owner of the land likewise has the exclusive right to the use of the surface for the purpose of drilling for and reducing to possession whatever oil and gas may lie below the surface, but in this state such right in the minerals can *not* be permanently sold and separated from the ownership of the balance of the land. On the basis of the civil law which obtains in Louisiana a so-called "sale" of the minerals conveys only a limited right known as a "servitude," similar to a right-of-way or what would be known to the common law as an easement. This "servitude" can not last for a period of more than 10 years unless it actually is exercised on some part of the land within that period of time by means of actual good-faith drilling operations in search of oil and gas production. So, therefore, if one buys mineral rights in Louisiana land such rights may be lost automatically upon the expiration of 10 years from the date of purchase from the owner of the surface. Although formerly looked upon as a hardship, this rule works very well in practice as it prevents tying-up of minerals for too long a period of time without securing development of the mineral possibilities of the property. An advantage from the mineral owner's standpoint is the fact that such mineral interest is not subject to taxation.

RIGHTS AND OBLIGATIONS OF LESSEES

As a consequence of the fugacious characteristics of oil and gas when once a means of escape from the natural reservoir within which they have been confined is provided by drilling operations, highly competitive drilling campaigns formerly were the order of the day. As soon as production was secured on one owner's land, there followed a wild scramble to drill on the surrounding leases in order that each operator might obtain as much production as possible before the recoverable oil was drained away by others. This was, of course, a highly wasteful procedure. But, under the theory of the law that every owner may use his land as he sees fit, so long as he does no affirmative direct injury to his neighbor, there was no alternative. The only protection was more and more drilling as a sort of self-defense against what the adjacent owners and lessees were doing. There became established in the law the principle that a lessee was under the duty and obligation to drill as many wells on his lessor's land as was necessary to protect

that land from drainage which otherwise would result from wells drilled by others on surrounding leases. If a lessee failed to comply with this implied obligation, the lessor was entitled to cancellation of the lease, and, perhaps, damages for the amount of royalty loss he had sustained due to the lack of protection from drainage and consequent loss of oil. The judicial administration of this phase of the law marked the first important instance of the petroleum geologist actually participating in the determination of what result should be reached by the court in such cases. This was due to the fact that determination of whether or not the lease should be cancelled depended upon ascertainment of the existing facts as to the amount of drainage actually taking place, the amount of damage the owner had sustained, and the reasonableness of the lessee's diligence as determined by what a prudent and diligent operator would do under like circumstances. This presented a question, the correct determination of which was largely dependent upon the expert testimony of those familiar with the industry—the petroleum geologists and the production engineers, as well as supposedly impartial prudent operators. This field of the law of oil and gas continues to present some of the most troublesome and difficult cases. If those in possession of expert and technical knowledge concerning the production of oil and gas do not devise some better method than has yet put in an appearance for more accurately determining questions of drainage—how far it takes place, and the quantity of oil thereby lost—it is difficult to see how the lawyers and judges are going to arrive at any more certainty in the administration of this phase of the law. Also, the problem is made increasingly difficult from the standpoint of the landowner due to the fact that virtually the only expert and technical testimony available in such cases usually is furnished by the company geologists and production engineers, which is, to say the least, not entirely impartial.

Some difficult and interesting cases have arisen involving attempts by adjacent landowners to recover damages allegedly resulting from subsurface injury caused by negligent drilling on other property, as, for example, permitting a well to blow out, become uncontrollable, run wild and waste a large quantity of oil or gas. Assuming that sufficient acts of wrongdoing are established to make out a case of liability, the problem of determining the quantum of damages recoverable is largely one of securing sufficient expert geological testimony to establish the extent of injury to the land with reasonable legal certainty, keeping in mind the principle that the owner of the land does not own the oil and gas thereunder until he actually has reduced it to possession! Another type of trespass cause of action which should be of con-

siderable personal interest to petroleum geologists concerns trespasses committed incident to the conduct of geophysical prospecting without advance authorization or permission from the landowner. Some courts have allowed the recovery of very substantial judgments based upon supposed loss of large lease bonus values resulting from disclosure that the property exhibited poor potential prospects for the discovery and production of oil or gas. Recent tendencies, however, have been toward requiring stricter proof of actual loss, rather than allowing recovery of speculative damage. It is the writer's personal view that too great a burden of proof should not be imposed upon the unfortunate landowner.

Another source of extreme doubt and difficulty at the present time is the question of the liability for subsurface trespass in drilling operations, whether accidental or intentional. Formerly it was thought that all oil wells were drilled straight down, so that if the well was spudded in one owner's land it was believed that the bottom of the hole likewise was underneath that same tract. Now, of course, operators are able to survey the course of a well and determine the precise lateral location of the point of production. There have as yet been very few decided cases on the point. In two cases decided in California it was held that there was no liability in such a case, on the theory that only a single reservoir underlay both tracts of land and it had not been proved that the trespassing crooked well was producing any more oil than would have been the case if it had gone straight down.[3] It may some day be possible to determine the underlying geological conditions with sufficient certainty to arrive at a more definite result. Here, again, we have presented an occasion for expert testimony by the geologist. This matter of slant well drilling is now sought to be controlled by administrative regulations limiting the permissible total deviation of a well from the true vertical. The thoroughness of the administration of such regulations in some instances, however, may be a different story. Under the provisions of the 1936 Louisiana Conservation Statute the Commissioner of Conservation has the authority to require the filing with the commissioner of directional, as well as electrical logging, surveys of every well drilled. Such administrative power has not yet been exercised generally.

[3] Subsequent to the rendition of judgment by the trial courts in the two cases referred to, both judgments were reversed by the appellate courts. The final result was that the rights of the overlying owners were protected by the allowance of damages and the granting of injunctive relief restraining continuation of the underground trespass. *Union Oil Co. of California v. Reconstruction Oil Co.*, 66 P. (2d) 1215 (1937); *Alphonzo E. Bell Corp. v. Bell View Oil Syndicate*, 76 P. (2d) 167 (1938).

NEW CONCEPTION OF OIL PRODUCTION

During the past several years the oil industry largely has become committed to the establishment of a new economic order. The principal thesis of this new concept is the recognition of the fact that each oil producer and landowner in a particular producing area is entitled to receive his fair and equitable share of the recoverable oil in that pool, and no more. General adoption of this new conception will revolutionize the business of producing oil, and will cast into the discard many of the wasteful intensely competitive methods heretofore accepted as a necessary evil. The actual carrying out of the new plan is accomplished by unitization contracts whereby the interested parties pool their holdings and operate them as an entirety on a sort of joint basis. The putting of any such scheme into effect, however, is dependent on voluntary action of the parties, which in turn requires the discard of the spirit of intense individualism which has heretofore characterized operators as well as landowners.

The matter of reducing the economic and natural waste attendant upon unrestricted competitive development of oil and gas resources has, within the past few years, led most of the important oil- and gas-producing states to enact conservation laws to protect their mineral resources from waste. Waste is created when too many wells are drilled in a single producing area—not only the economic waste of useless drilling, but actual physical waste due to unnecessarily rapid loss of reservoir energy. Under these modern conservation laws it is possible to control the rates of production from individual wells and fields; to enforce ratable or uniform withdrawals over the entire area of each field; to control the spacing of new wells and restrict such drilling to a pattern appropriate to uniform withdrawals; to prevent excessive drilling in oil fields; to require the observance by operators of reasonable and appropriate regulations designed to protect the adjacent property from damage due to blow-outs and wild wells; and, finally, to limit production in accordance with prevailing market demand.

Such statutory regulation is authorized by the general police power possessed by every State as an inherent attribute of sovereignty, and such exercise of the police power in the interest of the greater general welfare is valid and constitutional so long as it amounts only to reasonable regulation, does not deprive anyone of his property without due process of law, or deny the equal protection of the law to all persons or interests similarly situated. Whether or not the administrative regulation carried out under these statutes falls within the limits of reasonableness just mentioned is again going to be determined

chiefly by the physical facts which must be established in most instances by the expert testimony of the petroleum geologists, and the geological information thereby made available to the courts.

Another field of the law vitally affecting the oil and gas industry is that of taxation. Here again the testimony of the geologist is essential in determining the value of producing areas for establishing a basis from which to calculate income tax depletion allowances. This value must be fixed by the owner in the light of conditions and circumstances known at the time tax payments first become due. In the case of oil and gas deposits, such value is based largely upon estimates of the quantity of recoverable oil and gas underlying the property, and in making such estimates chief reliance must be placed upon the expert testimony of petroleum geologists, using the most accurate information available and a method of calculation enjoying the greatest current acceptance in the industry.

CONCLUSION

In conclusion it may be said that occasions in which a definite part is played by the petroleum geologists in the development and administration of the law applicable to the various phases of the oil and gas industry are by no means restrictive. The writer is of the opinion that a better understanding by lawyers and courts of the correct geological factors present in many cases would have enabled the courts to develop a more satisfactory body of jurisprudence. Moreover, that need for competent geological advice continues at the present time to be an important factor in enabling lawyers to determine the rights of their clients in many situations. Every lawyer who engages in any considerable amount of oil and gas practice should attempt to acquire a working knowledge of the fundamental principles of petroleum geology—not for the purpose of acting as his own geologist, but for the purpose of being in a position to realize when he does stand in need of expert advice.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 1088-1096

EARLY DEVELOPMENT OF DRILLING PRACTICES IN KANAWHA COUNTY, WEST VIRGINIA[1]

J. E. BILLINGSLEY[2]
Charleston, West Virginia

ABSTRACT

The art of well drilling had been perfected long years before the drilling of the Drake well near Titusville. Definite oil markets and definite oil-price quotations were already in existence and on file. Natural gas was actively in industrial use. All this does not detract in the slightest from the accomplishment of Colonel Drake, who sold petroleum to an eagerly awaiting public at the opportune moment, thereby practically revolutionizing first the lighting problem and later the transportation problem.

Although claims have frequently been made to the contrary, there can be no doubt that the processes of well drilling, along with many of the appliances and tools used in those processes, were initiated in the Kanawha Valley of West Virginia and within a few miles of the present State Capitol. It is the writer's object to trace the development of this now very common and practical industry with the thought in mind that it may be of especial interest.

In order to go back to the genesis of the well-drilling operation, it is necessary to go into the early history of the salt industry as it was developed on the western side of the Blue Ridge, giving data and information published in various volumes, including some of the West Virginia Geological Survey and an article published in 1876 by Dr. J. P. Hale, one-time president of the West Virginia Historical Society.

The first recorded mention of the manufacture of salt west of the Alleghenies was by report from Mrs. Mary Ingles, who was captured in Montgomery County, Virginia, by a band of Shawnee Indians from the Scioto Valley in Ohio. Her capture occurred in 1753 and she was carried back to Ohio down the New, the Kanawha, and the Ohio rivers. She later fortunately escaped. On the trip down the Kanawha, the party stopped for several days at a salt spring on the Kanawha, now the Malden vicinity, where salt water was boiled and a quantity of salt was made and carried on to the Ohio country.

In the course of the next 50 years the Kanawha Valley was settled in large part by the soldiers who followed General Lewis to the battlefield at Point Pleasant, where the Kanawha joins the Ohio, and

[1] Read before joint meeting of the Appalachian Geological Society and the Field Trip group of the American Association of Petroleum Geologists, Charleston, West Virginia, October 12, 1937. Manuscript received, February 16, 1938.

[2] West Virginia Gas Corporation.

where the Indian chief Cornstalk was decisively defeated. During this time the Kanawha "Licks" were the source of supply for all the salt used in the valley and farther west.

One of the early land locations in the valley was made by John Dickinson of Virginia in 1785. The tract covered 502 acres and it was on and in the vicinity of this tract of land that the crude drilling processes, later greatly improved, had their beginning. The tract included the bottom land around the salt spring and to the mouth of Campbell's Creek. This stream is the present north boundary line of the Campbell's Creek Oriskany sand gas field. In 1794, partly on the basis of value in connection with the salt springs, Dickinson sold the tract to Joseph Ruffner of the Shenandoah Valley. The purchase price was 500 pounds sterling, with additional amounts conditional on the amount of salt manufactured and sold. Ruffner thereupon sold his Virginia properties and moved his family to Kanawha in 1795, purchasing also the 900 acres of land on which the city of Charleston now stands, it having been laid out as a village the year before. In 1797, Ruffner leased the use of salt water and the right to manufacture salt on his property to Elisha Brooks, who erected the first salt furnace in the western country. It consisted of 24 small kettles set in a double row with a flue underneath, a fire at one end, and a chimney at the other. His first drilling operation was to sink two or three hollow logs, called "gums," into the soil around the salt lick near the edge of the river. The salt water was taken from the gums by means of a bucket. At first approximately 150 pounds of salt per day was produced. It was sold at the plant for 8–10 cents per pound.

In 1806, the elder Ruffner having died in 1803, his two sons, David and Joseph, undertook to locate the source of the salt water and to secure a larger and richer salt-water supply, hoping to be able to take care of the large and increasing demand for salt from the Kanawha Licks. It was this procedure which resulted in the initiation of what at that time was deep drilling. Working on the theory that richer brine would be found at bed rock, and below the soft overburden around the "Great Buffalo Lick," which was near the river's edge and 12–14 rods in extent, they solved their difficulty in the following manner. A straight and hollow sycamore log, called a "gum," approximately 4 feet in inside diameter was selected and placed in an upright position in the mud at the "lick." With one man inside the log with a pick and shovel and others outside operating a bucket and swape arrangement, the log was eventually settled to a depth of 13 feet on what seemed to be rock bottom, but when this was broken up, a much leaner brine flowed into the hole. They moved back from the river and in the same

manner sank a hole 45 feet deep to the same level at which they had started at the river. They then selected an oak log, 20 feet in length, bored a 3½-inch hole through it with a long-shanked auger, put an iron point on it, and drove it through the sand and gravel to bed rock. This represented a 65-foot hole, but the salt water was still of low grade. Then they returned to the well at the river, sank it to bed rock at approximately 17 feet and after settling wedges under the log, thus almost completely shutting off the surface water, they secured a much better brine but in a small quantity. They then decided to drill inside the gum, following the procedure used by blasters in drilling holes in rock. They constructed a long iron drill stem with a 2½-inch chisel bit of steel and attached the upper end by rope to a spring pole. Drilling then proceeded slowly to a point 17 feet in the rock or a total depth of approximately 34 feet, where a stronger flow of good brine was encountered on November 1, 1807. By welding additional lengths to the drill stem they drilled 11 feet farther in the rock or to a total depth of 45 feet below the surface and 28 feet in the rock where the brine greatly increased in richness. Drilling was continued and at 40 feet in the rock and 58 feet below the surface an ample flow of brine was encountered and drilling was stopped. The next problem in the phraseology of to-day, was to tube and pack the hole so that the strong brine could be obtained without dilution from upper water. To fit the 2½-inch hole, two long wooden half-tubes were made, both hollowed out along their centers. These were fitted together and wrapped tightly with twine. A larger wrapping was secured to the lower end, and the contrivance was pushed down the hole to the proper place. The brine flowed up the tube into the gum and was taken by the bucket process to the kettles in the plant. This is the story of the first tubing and packing job, so far as the records show, certainly west of the Alleghenies and probably elsewhere. It occurred in January, 1808.

As illustrative of the success of this early venture, in the following month, the Ruffner brothers reduced the price of salt to 4 cents per pound, thus passing on to the public a part of the benefit derived from their ability to secure a stronger brine and thus reduce manufacturing costs.

In the meantime drilling of salt wells continued as the business increased in volume. Tubing of wells became a job for the tinner who made long tin tubes which he soldered together as they went in the hole. Copper later replaced tin and steel later replaced copper. The wool and twine packer of Ruffner was succeeded by the seed bag. This process was known as "bagging the well." It may be well to quote Dr. Hale at this point, from a statement dated many years ago.

In the manner of bagging the well, that is, in forming a watertight joint around the tube to shut off the weaker waters above from the stronger below, a simple arrangement, called a "seed bag" was fallen upon, which proved very effective, which has survived to this day, and has been adopted where-ever deep boring is done, as one of the standard appliances for the purpose for which it is used. This seed bag is made of buckskin, or soft calfskin sewed up like the sleeve of a coat or leg of a stocking; made 12 to 15 inches long, about the size of the hole and open at both ends; this is slipped over the tube and one end securely wrapped over knots placed on the tube to prevent slipping. Some six or eight inches of the bag is then filled with flaxseed, either alone or mixed with powdered gum tragacanth; the other end of the bag is then wrapped like the first and the tube is ready for the well. When to their places—and they are put down any depth, to hundreds of feet—the seed and gum soon swell from the water they absorb, till a close fit and watertight joint is made.

In 1828 the steam engine came into use for pumping the salt water and, again quoting from Dr. Hale as recorded in Volume 1 (a) of the West Virginia Geological Survey, "also for boring wells and various other uses."

In 1831, William "Billy" Morris, to quote again, "a very ingenious and successful practical well borer," invented what were then called the "slips" but which are now known as the "jars." This device is described as being

interposed between the heavy iron sinker, with its cutting chisel bit below and the line of auger poles above. Its object is to let the heavy sinker and bit have a clear, quick, cutting fall, unobstructed and unencumbered by the slower motion of the long line of auger poles above. In the case of fast auger or other tools in the well, they are also used to give heavy jars upward or downward, or both, to loosen them.

Billy Morris probably never realized any financial gain from this idea which he put into effect 106 years ago near Charleston, West Virginia, but it can be readily conceded that without the jars deep cable drilling would be most impractical.

To shift from the salt to the petroleum industry will require a little more detail and one or two quotations. All these salt wells produced from the Salt sands, but drilling continued to greater depth in Kanawha County, and "to the Corniferous Limestone which underlies the coal measures, known as the 'long running rock,' from the fact that a boring bit will run a long time in it without being dulled." This refers to the "Big lime" of present drillers or the Greenbrier. In many of these salt wells both oil and gas were encountered.

Many persons now think, trusting to their recollections, that some of the wells afforded as much as 25 to 50 barrels per day. This was allowed to flow over the top of the salt cisterns on the river, where from its specific gravity,

it spread over a large surface, and by its beautiful iridescent hues, and not very savoury odor, could be traced for many miles down the stream.

This was in the days when oil had nothing more to offer than a beautiful iridescence and a bad smell, but the day was approaching when a man named Drake would be very instrumental in selling this product to the investing public and thereby creating a very great industry.

It is apparent that for perhaps 30 years before the production of oil on Oil Creek, Pennsylvania, the drilling process was in regular use in Kanawha County, West Virginia, and elsewhere, and that considerable quantities of oil had been produced and thrown away as a nuisance. Incidentally, we understand that Drake employed men with experience from the Kanawha Valley, to drill his famous oil well at Titusville.

Turning to the historical aspects of the gas industry, it is noted that George Washington visited the Kanawha Valley, and in 1775 was the owner of land on which was a certain "burning spring" located 3 miles above the "Salt Lick," or evidently near the center of what is now the Campbells Creek Oriskany field; that the water bubbled from the gas which came from somewhere below, and which burned when lighted; that one William Tompkins in 1841 obtained gas in a salt water well and used it for "boiling his furnace." In 1843 the important event took place. Dickinson and Shrewsbury drilled a well approximately 1,000 feet in depth and

tapped nature's gas reservoir of this region. So great was the pressure of this gas and the force with which it was vented through this bore-hole, that the auger, consisting of a heavy iron sinker, weighing some 500 pounds, and several hundred feet more of auger poles [they still had neglected the cable], weighing in all perhaps 1000 pounds, was shot up out of the well like an arrow out of a cross-bow. With it came a column of salt water which stood probably 150 feet high. The roaring of this gas and water as they issued, could be heard under favorable conditions for several miles.

It is suggested by the author of the foregoing quotation that estimates of the volume of this combination of gas and salt-water well be taken *cum grano salis* (with a grain of salt). However, this was a real gas well and a sight for the stage-coach passenger who passed nearby, one of whom, a Harvard College professor, impelled by his desire for knowledge, lighted the flow and was badly burned. This gas was moved through wooden pipes to the nearest furnaces and used in the manufacture of salt. The gas in this well was also used to flow the salt water to the surface and for a mile through pipe lines and into a reservoir. It also lighted the premises at night. Other salt operators then drilled

so-called deep wells which were utilized in similar manner until the area was depleted of its gas content. This all preceded the Oil Creek drilling by 16 years.

The first record of a gas well in Kanawha County was in 1815 when a well within the present city limits of Charleston was drilled by Captain James Wilson in the usual search for salt water. This well found the place called a "cavity," developed a good flow of gas, caught fire, and presumably later was drowned out.

Leaving the Kanawha Valley, your attention is next directed to an article which appeared in the *American Journal of Science and Arts*, published in New Haven in February, 1826. The author was S. P. Hildreth, M. D., a resident of Marietta, Ohio, who wrote as follows.

> Two attempts at boring for salt water have been made in this country. The first was made two or three years since [1824] about 40 miles from Marietta, near the Muskingum River. [Evidently this must have been in the general vicinity of McConnellsville, now in Morgan County, Ohio.] They proceeded to a depth of about 200 feet. The other trial is now making, on the waters of Little Muskingum Creek, about 12 miles from Marietta. It is two years since they began to bore, working at it only in the summer and autumnal months. They have penetrated the rock to the depth of 300 feet and have as yet found no salt water. There is a continuous discharge of carbonated hydrogen gas from the well; and also from the bed of the creek on which the well is situated, at various places for the distance of half a mile. This gas is highly inflammable, and where there is a free discharge of it, it will take fire on the surface of the water on the application of a lighted stick or the flash of a gun and continue burning for days. It was this discharge of gas that induced the present proprietors to search for salt water, it being invariably found to accompany all the salt water of any consequence that has been discovered in the western country.

Note that this more than 300-foot drilling in Ohio occurred 33 years before the drilling of the Drake well and, in the last sentence of the quotation, the writer evidently refers to the drilling activity of the Kanawha Valley, this being the footnote inference of I. C. White. Continuing to quote from Dr. Hildreth,

> They commonly bore, at the wells of Little Muskingum, to the depth of 400 to 500 feet unless water is found before they reach that depth.

Especial attention is called to the next statement, made in 1826, which refers to two wells on Duck Creek, a few miles north of Washington County, in Guernsey County, Ohio.

> They have sunk two wells which are now more than 400 feet in depth. One of them affords a very strong and pure water, but not in great quantity. The other discharges such vast quantities of petroleum, or as it is vulgarly called, "Seneka Oil," and besides is subject to such tremendous explosions of gas, as to force out all the water and afford nothing but gas for several days, that

they make but little or no salt. Nevertheless the petroleum affords considerable profit and is beginning to be in demand for lamps, in workshops and manufactories. It affords a clear, brisk light when burnt this way, and will be a valuable article for lighting the street lamps in the future cities of Ohio.

It is conceded that these so-called "well borers" learned their trade in the Kanawha Valley of what was then the state of Virginia. Dr. Hildreth later visited the Kanawha Valley region as well as the valley of the Little Kanawha, meaning Ritchie County, West Virginia, and wrote to the same *American Journal of Science* in connection with these visits. In 1833, he wrote another article for the same publication, describing an oil well drilled in 1814 on the lands of "Mr. McKee" on Duck Creek, still presumably in the county of Guernsey, Ohio. This well was drilled to obtain salt water, but at a depth of 475 feet, to quote Dr. White, evidently in the Dunkard or Cow Run sand, a flowing oil well resulted, flowing "30 to 60 gallons at each eruption but now [1833] only one barrel weekly."

A few figures may be of interest, depicting transactions which occurred some years before the generally accepted discovery of oil on Oil Creek, Pennsylvania. These quotations are taken from the account books of a business firm in Marietta, Ohio, entitled "Transactions in Petroleum of Bosworth, Wells & Co., Marietta, Ohio, with Bushrod W. Creel, Hughes River, West Virginia." This account was taken from a publication of the West Virginia Geological Survey and from old account books at that time in the possession of Tasker W. Bosworth. These sales are selected at random.

Under date of October, 1848, we read of a sale of J. Shoonmacher, Pittsburgh, Pennsylvania, Seneca oil $149.00. Under date of September, 1850, we find a sale of Seneca oil to H. G. Farrell & Co., Peoria, Ill., amounting to $230.00. In May, 1849, B. A. Fahnestock & Co. of Pittsburgh bought $120.00 worth of Seneca oil. In 1851, Lynn, Smith & Co. of Philadelphia bought $167.36 worth of Seneca oil. In 1852, A. G. Bragg and Co. of Philadelphia bought Seneca oil to the extent of $1,804.00. Similar sales are recorded but unfortunately a price per barrel can not be found. Then we read the following.

The purchases from Bushrod W. Creel of Hughes River, West Virginia, began in 1847 and continued regularly up to 1860. The price paid Creel from the beginning of the trade up to 1857 was 33 cents per gallon, delivered at Marietta, Ohio. From 1857 to 1860 he was paid 40 cents per gallon.

On our present-day basis this latter would be $16.80 per barrel. On the credit side of the account with Mr. Creel, we read items like this.

January 1855, 24 barrels at 33 cents per gallon; September 1855, 27

barrels at 33 cents per gallon; December 1857, 153 barrels at 40 cents per gallon.

The following is quoted from I. C. White.

> There were, of course, petroleum sales from the Hughes River region as well as the Great Kanawha, to many other parties, but the transactions with Bosworth, Wells and Co. are the only ones yet discovered, of which a written record has been preserved. These records are of much historic interest, since, taken in connection with the petroleum discoveries in the Great Kanawha as early as 1808 as given by Dr. Hale, and those on the Muskingum, described by Dr. Hildreth in 1826, they show conclusively that a large [for the time] commercial business in petroleum was already in existence in Virginia and Ohio, both from drilled wells and sand pits, long before Col. Drake had completed [28th of August, 1859], near Titusville, Pa., the first well bored especially for petroleum.

The foregoing quotation has brought to attention another interesting vicinity from the standpoint of early oil and gas development, a vicinity where oil production has been actively in progress for approximately 90 years, the Hughes River development in Ritchie County, West Virginia, in 1844. The first oil in this area came from pits dug in the ground and was called "mud oil." Later in 1844, George S. Lemon drilled a well 100 feet deep for salt water, but got a small oil well. He saved the product by a syphon device which took off the accompanying salt water, and then began to sell oil. His property was later taken over by the enterprising Bushrod W. Creel, who made the oil sales previously noted, to Bosworth, Wells and Company of Marietta. This latter oil was called "rock oil" and commanded a 5-cent per gallon premium over "mud oil."

We now come to the last outstanding oil field of the very early days, still in active operation and to-day the scene of prospective Oriskany sand drilling. This is the Burning Springs area, named for a small village near the south end of the Volcano arch, the most pronounced structure in West Virginia, west of the mountains.

In 1842 the brothers Rathbone came to Parkersburg, West Virginia, from New York and purchased a 1,000-acre tract of land on Burning Springs Run, which was so named by the early settlers because on it were located two springs from which issued natural gas. Being obsessed with the same ideas about salt water discovery which seem to have been common to our predecessors, they drilled a well on their land, and were greatly disappointed when at 250 feet depth, they got a very good oil well, probably in the Burning Springs or Upper Freeport sand. This well was completed in 1859, shortly after Col. Drake completed his well near Titusville. As a result the Rathbones put their well to pumping and it was therefore the first oil well in the state

to be pumped for its oil yield alone. The first well in the state drilled purely for oil was also on the Rathbone land and was begun in the fall of 1859. It was a spring-pole job, of course, and was completed to 303 feet about May 1, 1860, and produced at the rate of 100 barrels per day from the Burning Springs or Upper Freeport sand. The Rathbone Oil Company was then organized and the second well, completed in 1860, came in at the rate of 40–50 barrels per hour. The lid was off at this point, and the village of Burning Springs shortly became a city of some thousands, the first oil boom town in West Virginia. But an anti-climax was in the offing. On a certain day in 1863, General Jones, riding at the head of some 3,000 Confederate cavalrymen, appeared on the scene, and when he left, the oil field, along with some 300,000 barrels of credit balances, was a smoking ruin, and thus passed the first big oil boom of West Virginia. The area never regained its early greatness, although it has produced a great amount of oil, and the writer has been informed that several wells of that early period are still producing. To-day various of the leading operating companies of the east are actively prospecting in this very area for oil and gas production in deeper and still deeper horizons.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 1097-1100

ANTICLINAL THEORY AND LATER DEVELOPMENTS IN WEST VIRGINIA[1]

PAUL H. PRICE[2]
Morgantown, West Virginia

When the importance of natural gas to industry was recognized, the more alert and progressive producers of oil turned their attention to a study of its occurrence.

While others had arrived at the same conclusion independently and some of them several years earlier, it was I. C. White, who was to become West Virginia's distinguished State geologist, to whom credit must be given for proof of the anticlinal theory of oil occurrence and for convincing the industry of its importance.

Dr. T. Sterry Hunt, the eminent Canadian geologist, was probably the first to recognize the principles involved in the anticlinal theory, having published a paper on the subject in the *Canadian Naturalist* in 1859, and another in the *American Journal of Science and Arts* for March, 1863.

Professor E. B. Andrews of Marietta, Ohio, also appears to have reached the same conclusions independently of Hunt, for in an article in the *American Journal of Science*, dated Marietta, May 20, 1861, descriptive of the "Oil Break" of West Virginia, the influence of anticlinal folds on the occurrence of oil and gas is distinctly announced.

F. W. Minshall of Marietta, Ohio, advocated the same views as Andrews, concerning the West Virginia "Oil Break," in a series of articles published in the summer of 1881.

Professor H. Hofer, the distinguished geologist of Leoben, Austria, also appears to have formulated the same conclusions from a study of the Pennsylvania oil fields in 1876, and published the elements of the anticlinal theory in his book, *The Petroleum Industry of North America*, pages 77–80, without any knowledge of the previous publications of Hunt and Andrews, while Newberry, Stevenson, and probably others had advocated the influences of rock disturbances as early as the seventies.

Thus, it appears that the theory had been recognized and its essential elements published, but the practical oil men had never heard of it in a way to make an impression on them, and the authors of the theory had made but slight attempts to apply its principles

[1] Read before the joint meeting of the Appalachian Geological Society and the Field Trip group of the American Association of Petroleum Geologists, Charleston, West Virginia, October 12, 1937. Manuscript received, October 24, 1937.

[2] State geologist.

practically in the location of new oil and gas fields. This is the work I. C. White especially accomplished and in the doing of it so enforced the lessons of geology upon the minds of the men engaged in the practical work of drilling for oil, that the structural theory is now generally accepted by them, as well as by geologists.

White was always liberal in acknowledging the aid of others, especially of Edward Orton, State geologist of Ohio, "whose acute mind and facile pen have done much to popularize and enforce the geological claims of the anticlinal theory."

White points out that the first oil producer to undertake, in a systematic way, the study of the occurrence of natural gas, was S. S. Vandergrift of Pittsburgh, Pennsylvania, then president of the Forest Oil Company and the United Pipe Lines.

In the Spring of 1883, William A. Earseman, a veteran oil operator, who was then in the employ of the Anchor Oil Company and who had noted the fact that many of the great gas wells of Pennsylvania were located along the lines where anticlinal axes had been drawn on the maps of the State Geological Survey of Pennsylvania, secured Vandergrift's assent and financial support to undertake a geological investigation of the occurrence of natural gas. Earseman then began a correspondence with White on the subject, the result of which was an engagement in which White agreed to devote the month of June, 1883, to an investigation of the subject for Vandergrift. White says:

> In this work I was often accompanied by Mr. Earseman, who communicated freely to me his ideas on the subject of anticlinals, though he did not then possess the necessary geological attainments to enable him to verify or disprove his suspicions. After visiting and studying the geological surroundings of all the great gas wells that had been struck in the Appalachian district, the conclusion was reached that the rock disturbance caused by anticlinal waves was the main and important factor in the occurrence of both petroleum and natural gas, and this announcement was made to Mr. Vandergrift in a written report at the close of June, 1883.

During the next 2 years, the theory was submitted to several practical tests in the successful location of the Grapeville, Washington, and other great gas pools. Having thus verified the hypothesis, it was duly formulated and given to the public through the columns of *Science* in an article entitled "The Geology of Natural Gas," by I. C. White, in the issue of that journal dated June 26, 1885. To quote White further,

> But while we can state with confidence that all great gas wells are found on the anticlinal axes, the converse of this is not true, viz., that great gas wells may be found in all anticlinals. In a theory of this kind, the limitations become quite as important as, or even more so than the theory itself; and

hence I have given considerable thought to that side of the question, having formulated them into three or four general rules (which include practically all the known limitations to me, up to the present time, that should be placed on the statement that large gas wells may be obtained on anticlinal folds) viz.,

(a) The arch in the rocks must be one of considerable magnitude.

(b) A coarse or porous sandstone of considerable thickness, or if a fine-grained rock, one that would have extensive fissures, and thus in either case be rendered capable of acting as a reservoir for the gas, must underlie the surface at a depth of several hundred feet (500–2,500).

(c) Probably very few or none of the grand arches along the mountain ranges will be found holding gas in large quantity, since in such cases the disturbance of the stratification has been so profound that all the natural gas generated in the past would long ago have escaped into the air through fissures that traverse all the beds.

(d) Another limitation might possibly be added, which would confine the areas where large gas flows may be obtained to those underlain by a considerable thickness of bituminous shale.

(e) Very fair gas wells may also be obtained for a considerable distance down the slopes from the crests of the anticlinals provided the dip be sufficiently rapid, or especially if it be irregular or interrupted with slight crumples. And even in regions where there are no well-marked anticlinals if the dip be somewhat rapid and irregular, rather large gas wells may occasionally be found, if all other conditions are favorable.

The reason why natural gas should collect under the arches of the rocks is sufficiently plain, from a consideration of its volatile nature. Then, too, the extensive fissuring of the rock, which appears necessary to form a capacious reservoir for a large gas well, would take place most readily along the anticlinals where the tension in bending would be greatest.

The conclusions announced by White were criticized by Charles Ashburner, geologist in charge of the Geological Survey of Pennsylvania, who claimed, in effect, that the relation between gas wells and anticlinals was one of coincidence merely, or of the same nature as Angell's "belt theory" of oil, and also that large gas wells could be found in synclines.

To this criticism White said, among other things,

My excuse for writing the article on natural gas was that I might be of some service in preventing the waste of capital that has been going on within a radius of 50 miles of Pittsburgh by the indiscriminate search for natural gas; and it is sufficient answer to Mr. Ashburner's criticism to point him to the brilliant lights along the crests of Waynesburg, Pinhook, Washington, Bull Creek, Bradys Bend, Hickory, Wellsburg, Raccoon, and other anticlinals, and also the darkness that envelopes the intervening synclines, in which hundreds of thousands of dollars have been invested without developing a single profitable gas well. [In other words, the proof of the pudding is in the eating.]

White further states

Mr. Ashburner can, if he chooses, interpret these facts as mere coinci-

dences, and explain them to himself as having no more bearing on the question of finding gas than "Angell's belt theory" of oil, but the practical gas operator can no longer be deluded by such logic as risking his money in water holes (synclines) where so many thousands have been hopelessly squandered.

While the anticlinal theory was probably the greatest single contribution to the location of oil and gas, it still left many questions unanswered. More than 50 years have elapsed since this excellent working hypothesis was advanced, but as a matter of fact there are even yet several uncertainties in connection with getting productive wells. For example, where are the structural "highs" in the Appalachian field on possible producing horizons below the Devonian shales? We know that we have a great thickening of these shales to the northeast and also a great thickening of the Pottsville measures to the south. We also know that convergence of strata causes migration of subsurface structures in relation to structures mapped on surface key beds. What has controlled the porosity of our deep sands and where will this porosity, sufficient for production, be found? Did these hydrocarbons find their way into porous horizons, or does their presence account for the porosity? What was the depositional environment of the Oriskany, the Medina, the Trenton? What is the source material and chemistry of that material from the time of its deposition until it becomes either petroleum, or natural gas, or both? It is not necessary for me to emphasize to this group the unknowns or to point to their importance in the successful location and recovery of these much sought fuels. It is almost surprising how generally successful the search has been, considering the lack of these fundamental data. But if we knew the answers to these questions, together with the tectonic history of the geosynclinal area, our methods of search could be more orderly.

Much progress, however, has been made and greater progress is now being made. The methods and technique in handling these problems have greatly advanced. Most State geological surveys are given little encouragement, and less financial aid, to carry on such important researches. It is especially pleasing that the administration and the legislative body of West Virginia recognize the importance and value of geologic work, and because they have so recognized it, this Survey has, over a long period of years, been able to carry on investigations and publish reports and maps that are of great value to the geologists and to the petroleum industry.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 1101-1107

GEOLOGICAL NOTES

SECOND VENEZUELAN GEOLOGICAL CONGRESS, SAN CRISTOBAL, APRIL 1-7, 1938: ABSTRACTS[1]

H. D. HEDBERG[2]
Ciudad Bolivar, Venezuela

The Second Venezuelan Geological Congress was held in the city of San Cristobal, State of Tachira, Venezuela, on April 1–7, 1938. This congress was organized by the Servicio Tecnico de Geologia y Mineria, a division of the Ministerio de Fomento of the Venezuelan Government, and was attended by 84 persons of whom the majority were geologists and petroleum engineers from Venezuela, Trinidad, and Colombia. Fifteen papers on the geology of Trinidad and Venezuela were presented and several days were spent in field excursions to points of geological interest in the State of Tachira and adjoining areas.

The city of San Cristobal, situated in the foothills of the Andes in the southwestern corner of the republic at an elevation of 2,900 feet, proved an excellent site for the Congress. Formal meetings were held in the beautiful new Salon de Lectura, the opening of which coincided with the Congress. Three or four full-day field excursions were interspersed with the regular sessions at which papers were presented and discussed. These excursions were ably led by L. Kehrer of the Caribbean Petroleum Company, whose experience in the geology of this region made these trips especially worth while.

A particularly interesting feature connected with the Congress was the trip over the Trans-Andean highway from Caracas to San Cristobal by means of which the majority of those attending the Congress arrived at the meeting place. This 685-mile trip over an excellent mountain road reaching altitudes of more than 13,000 feet was completely organized by the members of the Servicio and was made in a fleet of 25 cars, trucks, and trailers. Comfortable overnight camps were established for the party along the way near Barquisimeto, Valera, and Lagunillas. Four days were spent in making the trip in order to allow opportunities for enjoying the magnificent Andean scenery and for studying and collecting in important geological localities.

Members of the American Association of Petroleum Geologists,

[1] Manuscript received, May 15, 1938.

[2] Mene Grande Oil Company, Apartado 35.

of whom 22 were present, take this opportunity of expressing their gratitude and appreciation to Nestor Luis Perez, Ministro de Fomento, and to the members of the Servicio Tecnico de Geologia y Mineria: Guillermo Zuloaga (secretary), S. E. Aguerrevere, Manuel Tello, V. M. Lopez, and Carlos Freeman, and to many others who contributed to the success of this Congress. The whole affair was handled in the inimitable manner which characterized last year's Congress in Caracas. While on the trip from Caracas to San Cristobal and throughout the stay at San Cristobal, those attending the Congress were the guests of the Venezuelan Government and nothing was spared in providing for their comfort and convenience.

Papers (and discussions) will be published shortly in special volumes in both Spanish and English. These, as well as the volumes containing the papers presented at last year's Congress in Caracas, may be obtained from the Servicio Tecnico de Mineria y Geologia, Ministerio de Fomento, Caracas.

At the close of the meetings, on behalf of the geologists from Trinidad, H. Kugler of the Trinidad Leaseholds, Ltd., presented to those attending the San Cristobal Congress an invitation to a geological convention in Trinidad, which will be held in March or April, 1939.

ABSTRACTS

The following abstracts of papers presented at the Second Venezuelan Geological Congress have been obtained through the coöperation of the Servicio Tecnico de Geologia y Mineria.

Gerth, H. (Professor of Paleontology, Geological Institute, University of Amsterdam): Outlines of the Geological History of the South American Cordillera.

The author especially points out the great difference between the main part of the Cordillera with a principally meridional direction and the two ends of this chain, at the northern and southern extremities of the continent, which tend to a more nearly equatorial direction. In the former part we have to do with the border of an old continent, faulted down during older Mesozoic time and then flooded by numerous transgressions of the Pacific Ocean. At the end of the Mesozoic era this part of the Cordillera was raised up by block faulting accompanied by enormous magmatic activity—intrusive as well as effusive. Folding is of secondary character and prevails only in the eastern ranges.

In contrast, the northern and southern parts of the Cordillera were high regions during older Mesozoic times, permitting only insignificant marine sedimentation during this time. But in the Lower Cretaceous these parts of the continent began to sink and a big series of Cretaceous and older Tertiary sediments were deposited there. These sediments were strongly folded during Tertiary time without magmatic activity in any way comparable to that of the meridional part of the Cordillera but the sediments were partly changed

by dynamic metamorphism unknown in the main part of the Cordillera. In this respect these northern and southern parts of the Cordillera with more nearly equatorial trends are more similar to the mountains of the Alpine system. (Author's abstract.)

TOMALIN, W. G. C. (Caribbean Petroleum Company, Maracaibo): Stratigraphy of Cretaceous Formations in the Neighborhood of the Rio Carache Valley, State of Trujillo.

A topographical map (scale, 1:50,000) showing localities is submitted together with a schematic cross section along the Trans-Andean Highway where it follows the Carache Valley. The Cretaceous formations discussed comprise the Colon shale (Upper Cretaceous), La Luna-Cogollo (Middle Cretaceous), and the Tomon (Lower Cretaceous), Thicknesses of 500, 400, and 800 meters respectively have been measured. A columnar section extending from the overlying Misoa-Trujillo formation to the unconformable contact of the Cretaceous with the Mucuchachi formation is also given. Paleontological determinations by Mr. Rainwater are summarized. The occurrence of *Orbitolina concava* (Lamarck) var. *texana* (Roemer) is reported from limestone beds near the base of the Tomon and the relationship with the Glen Rose formation of Texas is discussed. (Author's abstract.)

KUNDIG, E. (Royal Dutch Shell, The Hague): The Pre-Cretaceous Rocks of the Central Venezuelan Andes with Some Remarks about the Tectonics.

The author discusses the petrology of pre-Cretaceous rocks in the central Venezuelan Andes. It is particularly concerned with the metamorphic and igneous rocks of supposed early Paleozoic age and the La Quinta (Red-bed) formation. A type section is designated for the La Quinta formation and new evidence (based on fossil fish remains) is presented for its Jurassic age.

KEHRER, L. (Caribbean Petroleum Company, Maracaibo): Some Observations on the Stratigraphy of the States of Tachira and Merida in Southwestern Venezuela.

This paper treats of the stratigraphy of the states of Tachira and Merida. The section includes sediments of Miocene, Eocene, Cretaceous, Jurassic, Permo-Carboniferous, Devonian?, and Ordovician ages. Fossil lists are given for several of the formations.

MANGER, G. E. (Mene Grande Oil Company, Maracaibo): Notes on the Stratigraphy of the Younger Tertiary Formations of the District of Bolivar, State of Zulia, Venezuela.

This paper discusses the younger Tertiary formations of the Bolivar Coastal Fields (La Rosa, Lagunillas, La Villa, La Puerta, Onia, and El Milagro formations). It deals principally with the zonation of the La Rosa and Lagunillas formations, the lateral intergradation of these two formations, and the direction of marine incursion in the Tia Juana field. Due to the nonmarine character of the section above the La Rosa formation, conclusions on correlation are based largely on lithology and mineralogy. Stratigraphic relations between the several formations are discussed. (Author's abstract.)

DOUGLAS, J. G. (Mene Grande Oil Company, Maracaibo): Fresh-Water Resources of the Bolivar Coastal Fields.

The increasing need for an adequate drinking water supply and for fresh water suitable for boiler use has stimulated petroleum companies to make

efforts to find such a supply in the vicinity of their camps. A brief lithologic description of the formations which carry fresh water sands is presented and the results of important tests for fresh water are taken up individually. The assistance obtained from electrical logs taken in numerous oil wells is demonstrated and chemical analyses are presented in chart form, grouped according to the formation in which the aquifers are found.

HOFFMEISTER, W. S. (Lago Petroleum Corporation, Maracaibo): Aspect and Zonation of the Molluscan Fauna in the La Rosa and Lagunillas Formations, Bolivar Coastal Fields, Venezuela.

The La Rosa formation can be separated according to macrofaunal content into a lower division, *Cadulus* zone, and an upper division, *Microdrillia* zone. On foraminiferal evidence the writer divided this later zone into a lower horizon, *Bolivina* sub-zone, and an upper horizon, *Cibicides* sub-zone. The aspect of the La Rosa fauna points to a tropical sea of shallow or moderate depth. The close affinity of the La Rosa fauna to the classic Lower or Middle Miocene faunas of the Caribbean region testifies for a Miocene age, preferably Lower Miocene.

A thin shallow marine fossil horizon known as the *Lithophaga* zone is found near the middle of the Lagunillas formation. Because of its wide lateral extent and the ease of recognition the *Lithophaga* zone is a valuable marker throughout most of the length of the Bolivar coastal fields. A Lower to Middle Miocene age has been assigned to the Lagunillas formation.

The author correlates the La Rosa formation with the upper Agua Clara formation of Falcon and the Lagunillas formation with the Cerro Pelado formation of the State of Falcon. (Author's abstract.)

GONZALEZ DE JUANA, C. (Ministerio de Obras Publicas, Caracas): Contributions to the Geology of the Zulia-Falcon Basin.

It has been determined by field observations and by actual drilling that the Oligocene formations, San Luis and Agua Clara, gradually thin from south to north and disappear along an east-northeast west-southwest line extending from the Isthmus of Paraguana to Maracaibo. Therefore, the existence of an Oligocene dry land in the northern part of northwestern Venezuela bordering the "Falconian channel" is reasonably certain. During Lower or Middle Miocene time the sinking of this dry land reversed the sedimentary conditions at the time of the great La Puerta unconformity. Since that time the shore line has been approximately parallel to the present one. (Author's abstract.)

DALLMUS, K. F. (Standard Oil Company of Venezuela, Caripito): Geology of El Valle de Guanape Area, District of Bruzual, Anzoategui.

The area lies in northwestern Anzoategui and northeastern Guarico. Under the heading of geography the author discusses physiography, drainage, vegetation, and population. The geological part of the paper deals principally with the stratigraphy of the Santa Ines formation (Miocene) and the Carapita formation (Oligocene-Miocene). It touches more briefly on Eocene sediments (Merecure formation?) and on Cretaceous sediments and pre-Cretaceous (?) metamorphics. The major structural feature of the area is a series of thrust faults of great horizontal displacement by which the metamorphics have been pushed over the Cretaceous and the Cretaceous and Eocene in turn over the Oligo-Miocene.

AGUERREVERE, S. E., and LOPEZ, V. M. (Servicio Tecnico de Mineria y Geologia, Ministerio de Fomento, Caracas): The Geology of the Island Gran Roque and Its Phosphatic Deposits.

Gran Roque is situated at the extreme north of the archipelago Los Roques and lies about 144 kilometers N. 10° E. from the seaport of La Guaira, Venezuela. The island is composed chiefly of a body of gabbro and diabase which has been intruded by pegmatite dikes and apophyses of granodiorite. From the local geology no age criteria can be established. The commercial phosphate deposits of the island are the result of a partial replacement of the gabbro effected by the chemically active part of the guano on greatly sheared zones within the gabbro. (Authors' abstract.)

KNECHTEL, M. M. (U. S. Geological Survey, Washington): Pre-Cretaceous Rocks in the State of Barinas, Venezuela.

The author discusses the paper on the geology of the Barinas area which was presented by A. N. Mackenzie at last year's congress in Caracas and gives additional data on the pre-Cretaceous rocks of this area.

REGAN, J. H. (Standard Oil Company of Venezuela): Notes on the Quiriquire Field.

This is a compilation of written work by A. J. Freie on the stratigraphy and theory of oil accumulation in the Quiriquire field of eastern Venezuela. It also presents a summary of the history, present development, and structure of the field. (Author's abstract.)

KUGLER, H. (Trinidad Leasholds, Ltd., Trinidad, B.W.I.): Geology of Soldado Rock between Venezuela and Trinidad.

The author reviews the history of the geological investigation of this island which has been of so much importance with regard to the stratigraphy of the Caribbean region. He then presents the results of his own most recent work (an earlier paper by the author was published in 1923) accompanied by a detailed geologic map (scale, 1:500) and several cross sections. Paleontologic work which is now being carried out in both America and Europe on detailed collections from this island confirms the presence of Paleocene rocks unconformably overlain by Upper Eocene sediments. Thus far, however, the previously postulated unconformity within the Upper Eocene has not been definitely proved. The author gives an interpretation of the interesting tectonic and sedimentary structures shown on the island. The paper is dedicated to the memory of Carlotta J. Maury, a pioneer worker on the paleontology of this island, who died in January of this year.

HUTCHISON, A. G. (United British Oilfields of Trinidad, Point Fortin, Trinidad): Notes on the Cretaceous of Trinidad.

This paper furnishes a tentative correlation of certain Trinidad beds, principally from the Northern and Central Ranges, with the eastern Venezuelan Cretaceous succession as described by Hollis D. Hedberg for the Rio Querecual section. The age of many shales could be inferred from that of the associated fossiliferous limestones if the author's views were accepted that these limestones were lenses indigenous to the formation and not derived blocks. (Author's abstract.)

JOHNSON, G. D. (Standard Oil Company of Venezuela, Caripito): Some Alteration Products in Miocene Clays of Guarico.

Abundant gypsum in carbonaceous clays is shown to be entirely secondary—derived from limestone and pyrite. Cemented clay-pebble beds ("pudding stones") appear to occur in the Miocene section and are seen forming at present in the beds of intermittent streams. (Author's abstract.)

DEEP WELL NEAR MARLOW, STEPHENS COUNTY, OKLAHOMA[1]

E. A. PASCHAL[2]
Oklahoma City, Oklahoma

A well of interest to the industry has been drilled by the Coline Oil Corporation in Sec. 1, T. 2 N., R. 8 W. near Marlow, in Stephens County, Oklahoma. At the total depth of 10,000 feet, the well was still in beds of Pennsylvanian age. It was later plugged back to test a sand at 8,995–9,098 feet which showed oil and gas in the drill cuttings. The well is now making 40–50 barrels of oil per day on gas lift, but due to mechanical difficulties, it has not been properly completed, and this is not considered a true test of its probable potential. A detail sample log of the well, made by C. T. Casebeer, has been filed with the Oklahoma State Corporation Commission, Oklahoma City, copies of which may be secured from the Well Log Division of the Commission for 50 cents each.

This well was drilled on a surface structure, the west end of which was discovered by the writer in the latter part of 1923. It was later mapped in more detail by the writer and C. T. Casebeer during the winter of 1934–35.

The structure is reflected by beds within the Marlow member of the Whitehorse formation of Permian age, and by the contact of the top of the Marlow with the Rush Springs member. It is difficult, if not impossible, to work the entire structure from surface exposures because the topography rises toward the east and the top of the Marlow member is not exposed. No attempt has been made to map beds within the Rush Springs member, but samples from a hand drill and records of water and oil wells lead to the conclusion that the structure may be one of major proportions. No machine drill work has been done, but it would be relatively simple and comparatively inexpensive definitely to determine its size and extent by drilling to the contact at the base of the Marlow member which can be readily identified from well cuttings.

It is also interesting to note that the surface structure is located on a topographic "high."

[1] Manuscript received, June 13, 1938.

[2] Coline Oil Corporation.

TENTATIVE CORRELATION OF FORMATIONS IN COLINE OIL CORPORATION'S JOHNSON NO. 1, SW. ¼, SE. ¼, NE. ¼, SEC. 1, T. 2 N., R 8 W., STEPHENS COUNTY, OKLAHOMA

Depth in Feet	*Formation*
0–65	RUSH SPRINGS member of Whitehorse formation. Predominantly soft red sand
200	MARLOW member of Whitehorse formation. Predominantly red shale and gypsiferous sands
770	DUNCAN or CHICKASHA-DUNCAN. Predominantly purple and red sands
1,393	HENNESSEY. Red shale with green sand streaks
1,7[illegible]5	GARBER. Red and green sands and sandy limestones interbedded with red shale
3,705	WELLINGTON. Predominantly brown shale with thin sands
4,780	PONTOTOC. 3,705–4,150 feet, predominantly brown shales and limestone conglomerates with some feldspar; 4,150–4,780 feet, predominantly blue and brown shales with arkosic sands and sandy limestones
Unconformity.	Arbuckle orogenic phase (van der Gracht)
6,210	UPPER HOXBAR. Blue and brown shales with cherty sands
6,930(?)	LOWER HOXBAR. Limestones containing *Fusulina*. Also blue and brown shales with calcareous sands
10,000	DEESE. 6,930–7,580 feet, predominantly gray and brown shales with calcareous sands; 7,580–8,055, predominantly gray and brown shales with thick cherty sands; 8,055–8,310, predominantly gray and maroon shales with thin sands; 8,310–9,205, predominantly vari-colored shales with very hard cherty sands. Schlumberger electric log shows six sands having high resistivity indicating oil and gas between 8,613 and 9,206 feet. 9,205–10,000 feet, predominantly bluish gray shales with thin calcareous sands

---

CHAPEL HILL POOL, SMITH COUNTY, TEXAS[1]

F. H. LAHEE[2]
Dallas, Texas

A new pool is indicated in East Texas in H. L. Hunt's Bradley No. 1, completed in July, 1938. This well is located near the center of the Thomas P. Payne Survey, about a mile south of Chapel Hill, and 10 miles east of Tyler, in Smith County. A recent test indicated approximately 72 barrels of greenish distillate and 850,000 cubic feet of gas in 24 hours through a ⅛-inch choke. This production is coming from a porous zone in the upper part of the Lower Glen Rose, between depths of 7,330 and 7,528 feet, the total depth of the hole. This is the same zone that includes several of the Rodessa "pays." The producing formation is said to be oölitic and coquina-like limestone.

Location for this well was made for Hunt by the geological department of the Sun Oil Company near the center of an anticlinal structure at first suggested by field mapping, core drilling, and subsurface mapping by this company in 1931, supplemented by further subsurface work in 1934 and 1935, and subsequently confirmed by reflection seismography in 1937. The discovery is definitely to be attributed to geology, but confirmed by geophysics.

[1] Manuscript received, July 18, 1938.

[2] Chief geologist, Sun Oil Company.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 1108-1111

DISCUSSION

CONDITIONS OF SEDIMENTATION AND SOURCES OF THE ORISKANY SANDSTONE AS INDICATED BY PETROLOGY, BY MARCELLUS H. STOW

DISCUSSION BY ARTHUR B. CLEAVES[1]
Harrisburg, Pennsylvania

Reports concerning the Oriskany group in the state of Pennsylvania are of increasing importance and interest to the oil and gas producers in the Commonwealth. Since the discovery of the Oriskany sand as a source of gas in Pennsylvania, that stratum has been increasingly exploited. Consequently accurate scientific detail concerning the Oriskany beds, the strata of the underlying Helderberg group and the overlying Onondaga group has assumed greater importance than ever before. Recent excellent work has already been published on the Helderberg and Onondaga groups in Pennsylvania by Frank M. Swartz[2] and Bradford Willard.[3] The writer has already published a brief synopsis of Oriskany thicknesses in Pennsylvania[4] and has in progress a comprehensive study of the Oriskany group.

It is with sincere regret that errors and inaccuracies were noted in the recent paper by Marcellus H. Stow in the May issue of the *Bulletin*.[5] The writer has no adverse criticism of that part of Dr. Stow's paper wherein it deals with the petrology of the Oriskany (Ridgeley in Pennsylvania) sandstone, in fact those data are valuable additions to our knowledge of the Oriskany, but he believes it incumbent upon him to correct certain stratigraphic inaccuracies.

On page 543, line 10, Dr. Stow is discussing the stratigraphic position of the Ridgeley (Oriskany) sandstone.

> In other words, the formation examined lies between the overlying Romney shale and the Helderberg limestone in Virginia and Maryland, between the Marcellus shale and the Helderberg limestone in West Virginia, between the Marcellus shale and the underlying Stormville shale in Pennsylvania . . .

In reference to Pennsylvania in this paragraph the occurrence of the Onondaga formation, which is ubiquitous over most of the state, and which is found between the Marcellus shale and the Oriskany sandstone, is not mentioned. This omission is especially unfortunate and the oversight seems

[1] Geologist, Pennsylvania Topographic and Geologic Survey. Manuscript received, June 11, 1938. Published with the permission of the State geologist of Pennsylvania.

[2] Frank McKim Swartz, "The Helderberg Group from Central Pennsylvania to Southwestern Virginia," *Pennsylvania State College Min. Ind. Exp. Sta. Bull. 4* (1929); reprinted from *Proc. Pennsylvania Acad. Sci.*, Vol. III (1929).

[3] Bradford Willard, "The Onondaga Formation in Pennsylvania," *Jour. Geol.*, Vol. 44, No. 5 (1936), pp. 578-603.

[4] Arthur B. Cleaves, "Oriskany Thicknesses in Pennsylvania," *Proc. Pennsylvania Acad. Sci.*, Vol. 11 (1937), pp. 64-71.

[5] Marcellus H. Stow, "Conditions of Sedimentation and Sources of the Oriskany Sandstone as Indicated by Petrology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22, No. 5 (May, 1938), pp. 541-64.

strange in view of the splendid report of Willard on "The Onondaga Formation in Pennsylvania" published in 1936.[6]

In the same sentence the "Stormville shale" is mentioned as underlying the Oriskany sandstone. That name was given to a series of limy shales underlying the Oriskany sandstone in Monroe County, Pennsylvania, by I. C. White[7] in 1881, and was also used by him in his Second Geological Survey of Pennsylvania Reports of Progress: G.7 (Wyoming, Lackawanna, Luzerne, Columbia, Montour, and Northumberland counties), T.3 (Huntingdon County), and by his colleague E. V. D'Invilliers in the latter's Report of Progress, F.3 (Union, Snyder, Mifflin and Juniata counties). The use of the name "Stormville shale" is not permissible. In White's type region it is to-day apparent that he included within the term strata belonging to the Oriskany and to the New Scotland formation in the Helderberg group. This was determined by the writer in company with Frank M. Swartz during the field season of 1937 in eastern Pennsylvania. The writer was also aware of this fallacy during his field studies on the Oriskany in Huntingdon County in 1936, and his opinion is supported by the publication of "Geology and Mineral Resources of the Bellfonte Quadrangle, Pennsylvania"[8] by Charles Butts and Elwood S. Moore. On page 60 under the topic "Shriver Formation" they say:

> The Shriver formation was named from Shriver Ridge, near Cumberland, Maryland.[44] The same beds in Huntingdon County, Pennsylvania, were called "Stormville shale" by I. C. White, but as that name was applied by him to other units also, its further use is inadmissible.

Dr. Stow should say that the Ridgeley (or Oriskany) sandstone in Pennsylvania lies between the overlying Onondaga limestone or shale, as the case may be, and the underlying Shriver formation of the Oriskany group, or where in eastern Pennsylvania the Shriver can not be established because of paleontological deficiencies, the Lower Oriskany calcareous shales and cherts.

Under the heading "Oriskany Sections and Conditions of Sedimentation" the writer has fault to find with two sections. These sections are important because they occur near the Allegheny Front and their correct interpretation is necessary in view of the influence they may have on future drilling operations for Oriskany gas in the counties north and northwest of the areas involved.

On page 546, the last paragraph on the page, Dr. Stow says:

> At Jersey Shore, Lycoming County, Pennsylvania, a sharp contact of the Marcellus shale and the Helderberg limestone was observed. No Oriskany was present between them (Pl. 4, Fig. 2).

The implication here is that a considerable unconformity cuts out the entire Onondaga and Oriskany beds; such is not the case. Dr. Stow does not indicate where in the vicinity of Jersey Shore he secured his data, nevertheless a splendid Helderberg-Oriskany section may be studied one mile west of the limits

[6] Bradford Willard, *op. cit.*

[7] I. C. White, "Geology of Pike and Monroe Counties," *Second Geol. Survey of Pennsylvania Report of Progress G-6* (1881), pp. 123–24.

[8] *U. S. Geol. Survey Bull. 855* (1936).

of Jersey Shore on the east side of Pine Creek about one-fourth mile south of the bridge where the highway from Jersey Shore to Avis crosses Pine Creek. One-fourth of a mile south of this section another section of the Oriskany may be studied in the quarry of the Pine Creek Limestone Company. In these sections 93 feet of Ridgeley (Oriskany) sandstone and 81 feet of Shriver arenaceous shale are exposed. This gives an Oriskany thickness of 174 feet in the vicinity of Jersey Shore, refuting the implication that there is a marked unconformity of Lower and Lower Middle Devonian time in this area. Professor Frank Swartz gives a detailed section of the Helderberg and the Shriver at this locality in the publication already referred to; he differs from the writer in making the Shriver 90 feet thick instead of 81 feet.

Dr. Stow's failure to identify the Oriskany may have arisen over confusion of a barren, sooty, thin-bedded black shale that occurs overlying the New Scotland dense limestone and interbedded chert with the Marcellus, or with the Onondaga black shales of this region. The black shale overlying the New Scotland limestone and underlying the Shriver arenaceous shale has been assigned by the writer and by Dr. Swartz to the New Scotland. It commonly occurs in this stratigraphic position from the Maryland line north and northeastward in many sections in central Pennsylvania.

> One mile east of Montoursville, Lycoming County, in a complete section there are 65 feet of Ridgeley. It is clean, light colored, and loosely cemented. The Shriver is only partly exposed, but the stratigraphic interval between the Ridgeley and the New Scotland limestone would permit of 113 feet of Shriver provided there is no New Scotland shale member. . . . The interval of 21 miles between the Pine Creek and Montoursville sections has no Oriskany strata indicated on the State and County geological maps [Oriskany outcrops are present in Williamsport]. Thicknesses, however, at both ends of this interval strongly suggest their occurrence. The reason for non-exposure is accounted for by lateral planation by Bald Eagle Creek and burial in its flood-plain debris.

The foregoing quotation is taken from the writer's paper on "Oriskany Thicknesses in Pennsylvania."[9]

On page 549, the first paragraph, Dr. Stow discusses a section at Frankstown, Blair County, Pennsylvania. This is the classic section of the Shriver formation in Pennsylvania and was described in detail by Swartz in his paper on the Helderberg mentioned above. The relationships between the Ridgeley sandstone, Shriver chert, and the Helderberg are carefully delineated in Swartz's paper. Consequently, one fails to understand how Dr. Stow failed completely to recognize the Shriver in this section. The Shriver is an entity in itself containing its own distinctive fossils along with elements of the Helderberg and Ridgeley. The relationship can not be called a transitional one between the Helderberg and Oriskany sandstone.

At the end of the same paragraph mention is made of the Oriskany-Romney contact. The name Romney has no standing in the Pennsylvania stratigraphic column, has never been recognized by the Pennsylvania Geological Survey, and probably never will be, hence the term should not be used in the state of Pennsylvania where the Onondaga and Hamilton groups are so firmly established.

It is regrettable that more attention could not have been given to the current literature on the Lower Devonian in Pennsylvania by Dr. Stow and

[9] Arthur B. Cleaves, *op. cit.*, pp. 66–67.

less reliance placed on the antiquated reports and maps of the Second Pennsylvania Survey.

MARCELLUS H. STOW, Washington and Lee University, Lexington, Virginia (comment received, July 14, 1938): The introduction to the paper on the petrology of the Oriskany states that it is a petrographic study and presents tabulations of characteristic minerals and percentages with brief descriptions of these minerals, discussions of variation in thickness and lithologic character, conditions of sedimentation, and sources of sediments of the Oriskany formation from New York to West Virginia.

The writer appreciates Mr. Cleaves' compliments concerning this petrographic work.

It is well known that extensive stratigraphic studies of the Oriskany and adjacent formations are being made in the several states concerned, and that these studies are necessitating important revision of the stratigraphic nomenclature, but until these studies are completed and there is general agreement among the various investigators, it is quite fitting that the older and more familiar stratigraphic names be used for a general petrographic study over such a great area.

CORRECTION

RÉSUMÉ OF DEVELOPMENT IN EAST TEXAS DURING 1937

The following correction should be made in the article by E. A. Wendlandt and C. L. Herold, "Résumé of Development in East Texas during 1937," in the *Bulletin*, Vol. 22, No. 6 (June, 1938). On page 734, line 3 from bottom, the map location of the Gulf Oil Corporation's Robertson No. 1, shown as "(*8*)," should be "(*7*)" for correct location on Figure 1.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 1112-1116

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library and available to members and associates.

THE GERMAN ALPS AND THEIR ORIGIN, BY MAX RICHTER

REVIEW BY R. D. REED[1]
Los Angeles, California

Die deutschen Alpen und ihre Entstehung (The German Alps and Their Origin), by Max Richter. 179 pp., 56 figs. Gebrüder Borntraeger, Berlin (1937). Price, cloth, RM 4.80.

Of making many books about the geology of the Alps there is still no prospect of an end. In support of this great generalization, one of the few that might prove acceptable to all students of the subject, we may note several recent examples. In 1934 appeared Dr. J. Cadisch's volume, *Geologie der Schweizeralpen;* in 1935, Professor E. B. Bailey's *Tectonic Essays, Mainly Alpine;* in 1936, volume 1, *Der alpine Bauplan,* of Professor Ernst Kraus' *Der Abbau der Gebirge;* in 1937 the seventh installment, devoted to the Alps, of Professor F. X. Schaffer's *Geologische Landerkunde* (*Regionale Geologie*); and also in 1937 Professor Richter's little book which is the subject of the present review.

The German Alps, as the term was used before Anschluss when Professor Richter wrote, constitute only the northern margin, from Lake Constance to the Salzburg region, of the great East Alpine province. The thorny problems of the Hohe Tauern, of the Lower Engadine window, and of the Dinarids and their relations to more northerly zones, belong to areas beyond the limits of the district. As a glance at Professor Richter's book shows, however, the German Alps are not without thorny problems of their own. They have a Molasse belt, a Helvetic belt, a Flysch belt, and the north margin of an East Alpine belt; each with innumerable problems within itself and others with reference to its relations to its neighbors. And furthermore, as Professor Richter decides on page 1, the German Alps can be intelligently discussed only with reference to the general structure of the Alps as a whole.

The Introduction furnishes a clear and interesting general account of the German Alps as a geologic unit, its appearance, the presence of varied facies of certain formations, and a statement of the general relations of some of the more important thrust-sheets of which it is composed. Figure 1, a paleogeographic map with an indefinite but very small scale, is particularly illuminating, as is the physiographic sketch map, Figure 4.

The material that follows the Introduction is divided into sections of three different orders of importance, all unnumbered. The divisions of the first order will here be called chapters, the others sections.

Chapter 2—the Introduction serving under this scheme as Chapter 1—is devoted to the present landscape. In it the author discusses such subjects as the topographic expression of the different nappes, the valley systems, the occurrence of old erosion surfaces, and of remnants of earlier valleys now unused.

[1] The Texas Company. Manuscript received, June 25, 1938.

Chapter 3, divided into two sections, discusses the growth of the Alps into high mountains during Tertiary and Pleistocene; it is also largely physiographic. In the first section there is an interesting discussion of the Gipfelflur ("summit plain" or "summit level"), and of the less extensive but often confusing "levels" at different lower elevations. A table on page 27 illustrates the author's conclusions as to their origin and their relation to periods of thrusting, of valley-cutting, of warping, and of glaciation. The second section, that on the Pleistocene development of the Alps, deals pretty largely with glaciation. Penck and Brückner's classification (Günz, Mindel, Riss, and Würm) is followed.

The very long following chapter (90 pages) deals interestingly with the rocks and structure of the Calcareous Alps. In it may be found an excellent summary of the well-known, or often-mentioned, Alpine Mesozoic section with its many names and curious facies: of the Triassic with its northern "Germanic"and southern "Alpine" facies—Partnachschichten, Wettersteinkalk, Hauptdolomit, against Werfener Schichten, Hallstätter, Kalk, Ramsaudolomit, and the rest; of the Jurassic with its calcareous, siliceous, and marly facies, also with many names; and of the Cretaceous (Aptychus beds, Gosau beds and others). Tertiary strata are sparingly represented.

A later section of this chapter treats of the intra-Cretaceous orogenic phases that have now been shown to have played a far more important part in Alpine evolution than most earlier geologists suspected. The last and by far the largest part of the chapter is given over to an account of some of the structural details in five different areas: the Bregenz Forest, Lechtal Alps, and Allgäu; Ammergau and the Wetterstein; Karwendel and the Prealps between the Loisach and the Inn; Chiemgau Mountains and Kaisergebirge; the Reichenhall and Berchtesgaden Mountains. These sections, with their numerous references to local streams and places that are hard to find on most maps, are all right to study but not very easy to read. To a visitor at Berchtesgaden, who could keep his mind on the geology, the account of the Berchtesgaden Mountains would probably be thrilling; to a reader in America, with a heavy atlas at his side and a geologic map draped over his knees, it is less so. For this difficulty Professor Richter's illustrations, mostly structure sections not tied in to any maps, and a few of them too much reduced in scale for easy legibility, fail to furnish all the assistance that is likely to be needed.

The last three chapters deal respectively with the Flysch zone, the Helvetic zone, and the Molasse zone. Together they furnish an interesting and illuminating account of the Alpine marginal belt. Most interesting to oil geologists, perhaps, will be the references to the Tegernsee oil field, and the map and section, Figures 48 and 49, which illustrate its complexities. The oil occurs in rocks of the Helvetic facies and is found not far below a brecciated fault contact between the Helvetic rocks and the Flysch masses that have been thrust above them. The whole complex has been strongly folded after cessation of the thrust movements. As to the source of the oil, Professor Richter prefers the Molasse, a view in which Herbst and Teichmüller do not fully agree.[2] So far as the structural conditions are concerned, however, the two interpretations agree very well, as may be seen by comparing Richter's Figure 49 with Herbst and Teichmüller's Figure 1. Professor Richter suggests

[2] Georg Herbst und Rolf Teichmüller, "Die Erdöllagerstätte am Tegernsee (Oberbayern)," *Kali, verwandte Salze und Erdöl*, Heft 1–2 (1936).

that the detailed mapping carried out by himself and associates in this area is of considerable significance in connection with the oil occurrence, a view that can scarcely by doubted.

In summary, the volume under review is well written, well printed, well illustrated in the main, and well worth being owned and read by those whose taste or business leads them to delve into the literature of Alpine geology. As already suggested, a few of the structure sections are too greatly reduced in scale for comfort; and it may be added that a few more sketch maps, like Figures 1 and 4 but with generalized structural and stratigraphic data, would be welcome at least to those readers who live far away from the German Alps.

RECENT PUBLICATIONS

AFRICA

*"Les Gisements Petrolifères d'Egypte" (The Petroleum Beds of Egypt), by V. Stchepinsky. *Revue Petrol.*, No. 787 (May 27, 1938), p. 686.

CALIFORNIA

*"Torrance-Lomita Deep Development," by M. H. Soyster. *California Oil World* (Los Angeles), Vol. 31, No. 11 (June 5, 1938), pp. 9–10.

*"Eocene in the San Emigdio-Sunset Area," by Gerard Henny. *Ibid.*, pp. 17–21. Contains geological map and cross section.

CANADA

*"Age of the Selkirk and Rocky Mountain Uplifts in Canada," by P. S. Warren. *Amer. Jour. Sci.* (New Haven, Connecticut), Ser. 5, Vol. 36, No. 211 (July, 1938), pp. 66–71.

GENERAL

"Steinsalz und Kalisalze" (Rock Salt and Potash Salts), by Ernst Fulda. Includes an article on the Salt Deposits of Russia, by N. Polutoff. This book is Part 2 of Volume III (Coal, Salt and Petroleum) of *Deposits of Useful Minerals and Rocks, According to Form, Content, and Origin*, edited by Beyschlag, Krusch, and Vogt. 240 pp., 94 figs. Ferdinand Enke, Stuttgart (1938). Price: paper, RM 18.20; cloth, RM 20.

"Die Geologische Bedeutung von Gravimetermessungen" (The Geological Significance of Gravimetric Surveys), by J. Schander. *Bohrtechniker-Zeitung*, Jahr. 56, Heft 6 (1938), pp. 81–85.

*"Nomenclatorial Notes on Eocene Mollusca," by Katherine Van W. Palmer. *Bull. Amer. Paleon.* (Ithaca, N. Y.), Vol. 24, No. 80 (July 1, 1938), 7 pp.

*"Petroleum Development and Technology, 1938 (Petroleum Division)," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 127. "Papers and discussions presented before the division at meetings held at Los Angeles, Oct. 1, 1937; Oklahoma City, Oct. 7–9, 1937; New York, Feb. 14–18, 1938." Published by the Institute at office of secretary, 29 West 30th Street, New York. 744 pp. 6×9 inches. Cloth. Price, $5.00 net.

*"The Origin of Appalachian Drainage—A Reply," by J. Hoover Mackin.

Amer. Jour. Sci. (New Haven, Connecticut), Ser. 5, Vol. 36, No. 211 (July, 1938), pp. 27–54; 2 figs.

GEOPHYSICS

*"Geophysics Rôle in Deep Drilling," by J. Brian Eby. *World Petrol.* (New York), Vol. 9, No. 6 (July, 1938), p. 40.

GULF COAST

*"Probable Undiscovered Stratigraphic Traps on Gulf Coast," by Michel T. Halbouty. *World Petrol.* (New York), Vol. 9, No. 6 (June, 1938), pp. 27–39; 16 figs. of cross sections of oil fields; 22 figs. of possible traps; 2 pls.

ILLINOIS

*"Possible Producing Strata Existing below the McClosky in Illinois," by Alfred H. Bell. *Oil and Gas Jour.* (Tulsa), Vol. 37, No. 5 (June 16, 1938), pp. 30–31, 108; 4 figs. "Presented before Illinois-Indiana Petroleum Association Conference at Robinson, Illinois, on June 4, 1938."

MISSISSIPPI

*"Search for Oil in Southern Mississippi Encouraging," by Neil Williams. *Oil and Gas Jour.* (Tulsa), Vol. 37, No. 5 (June 16, 1938), pp. 21–22, 36; 1 fig., 1 map.

MOROCCO

*"Application of Electrical Methods to the Study of a Complex Structure, Le Tselfat, Morocco," by L. Migaux. *Oil Weekly* (Houston), Vol. 90, No. 3 (June 27, 1938), pp. 34–38.

OKLAHOMA

*"Traverse and Leveling in Oklahoma, Part I, Southwestern Oklahoma," compiled by N. E. Wolfard. *Oklahoma Geol. Survey Bull. 58* (Norman, 1938), 157 pp., 4 pls. Paper. 6×9 inches.

QUEBEC

*"Geology and Paleontology of the Mingan Islands, Quebec," by W. H. Twenhofel. *Geol. Soc. America Spec. Paper 11* (June 4, 1938). 132 pp., 1 fig., 24 pls. "With descriptions of Brachiopoda by W. H. Twenhofel and Marguerite Stiles Whiting, and a section on Cephalopoda by Aug. F. Foerste."

"Gas Naturali in Sicilia" (Natural Gases in Sicily), *Riv. Ital. del Petrolio* (Rome), No. 59 (March, 1938), pp. 10–13. *Review in *Revue de Geologie* (Liege), Vol. 18, Fasc. 6 (June, 1938), p. 406.

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Paleontology* (Tulsa, Oklahoma), Vol. 12, No. 4 (July, 1938).

"The Hackberry Assemblage—An Interesting Foraminiferal Fauna of Post-Vicksburg Age from Deep Wells in the Gulf Coast," by J. B. Garrett

"Conodonts from the Prairie du Chien (Lower Ordovician) Beds of the Upper Mississippi Valley," by W. M. Furnish

"Cephalopods from the Carboniferous Morrow Group of Northern Arkansas and Oklahoma," by A. K. Miller and Carl A. Moore

"The Gries Ranch Fauna (Oligocene) of Western Washington," by William Lloyd Effinger

"Upper Cretaceous Foraminifera from the Northwest Basin, Western Australia," by Irene Crespin

"A Permian Eurypterid from Oklahoma," by C. E. Decker

"The Preparation of Oriented Thin Sections and a Method of Cleaning Small Fossils," by Andrew H. McNair

Sky-line view of El Paso from scenic drive over Mount Franklin. Juarez, Old Mexico, in background. By courtesy of El Paso Chamber of Commerce and El Paso County Board of Development, Gateway Club, El Paso.

The mid-year meeting of the Association will be held at the Hotel Cortez, El Paso, Texas, September 27–October 2.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 1117-1126

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Howard L. Gentry, Jackson, Mich.
Richard A. Smith, R. B. Newcombe, B. F. Hake
John Jennings Larkin, Tulsa, Okla.
Frederic A. Bush, R. M. Gawthrop, Leslie A. Johnston
John Wesley Skinner, Midland, Tex.
J. Ben Carsey, John Emery Adams, V. C. Maley

FOR ASSOCIATE MEMBERSHIP

Charles Byron Bolar, Norman, Okla.
V. E. Monnett, Charles E. Decker, Robert H. Dott
William Robert Campbell, Barranca-Bermeja, Colombia, S. A.
W. W. Waring, Richard V. Hughes, O. C. Wheeler
James William Gwinn, Shreveport, La.
Walter K. Link, W. C. Spooner, E. B. Hutson
Marion E. Hestbeck, Shawnee, Okla.
Jack M. Copass, V. G. Hill, Dollie Radler Hall
Edward William Johnson, Enid, Okla.
Forrest W. Hood, Clinton R. Stauffer, Frank R. Clark
Kathleen Kirk, Tulsa, Okla.
V. E. Monnett, A. N. Murray, Dollie Radler Hall
Atlee George Manthos, Austin, Tex.
F. L. Whitney, H. B. Stenzel, E. H. Sellards
James Donald Ross, Manila, P. I.
G. D. Hanna, Max Krueger, Walter W. Heathman
Alfred E. Storm, Dallas, Tex.
Eugene McDermott, Cecil H. Green, J. C. Karcher
Daniel Jefferson White, Jr., Houston, Tex.
Joseph M. Wilson, Robert H. Cuyler, Fred M. Bullard
Robert Thompson White, Bakersfield, Calif.
Drexler Dana, Rollin Eckis, E. Wayne Galliher

FOR TRANSFER TO ACTIVE MEMBERSHIP

Stanley R. Allen, Houston, Tex.
Dave P. Carlton, Ben L. Pilcher, Paul B. Hunter
Leslie Bowling, Houston, Tex.
W. F. Bowman, Homer A. Noble, Wayne V. Jones
William Frank Bowser, El Dorado, Ark.

E. A. Koester, W. B. Weeks, A. F. Crider
Donald Owen Chapell, Tulsa, Okla.
Sherwood Buckstaff, Wesley Gish, R. E. Shutt
Robert I. Dickey, Midland, Tex.
Cary P. Butcher, Georges Vorbe, F. H. Schouten
Henry Emmett Gross, College Station, Tex.
Robert H. Dott, V. E. Monnett, W. F. Cloud
Robert G. Hamilton, Oklahoma City, Okla.
E. G. Leonardon, P. Charrin, A. C. Trowbridge
Castle J. C. Harvey, Houston, Tex.
Jack M. Copass, Jess Vernon, John L. Ferguson
A. A. Holston, Tyler, Tex.
R. B. Mitchell, G. W. Pirtle, Robert L. Jones
John W. Inkster, Wichita, Kan.
R. E. Shutt, W. C. Bean, Charles W. Roop
Harold D. Jenkins, Oklahoma City, Okla.
N. W. Bass, Chester F. Barnes, Charles E. Decker
Selden R. Self, Tyler, Tex.
J. F. Hosterman, A. R. Denison, Dollie Radler Hall

(Continued on page 1131)

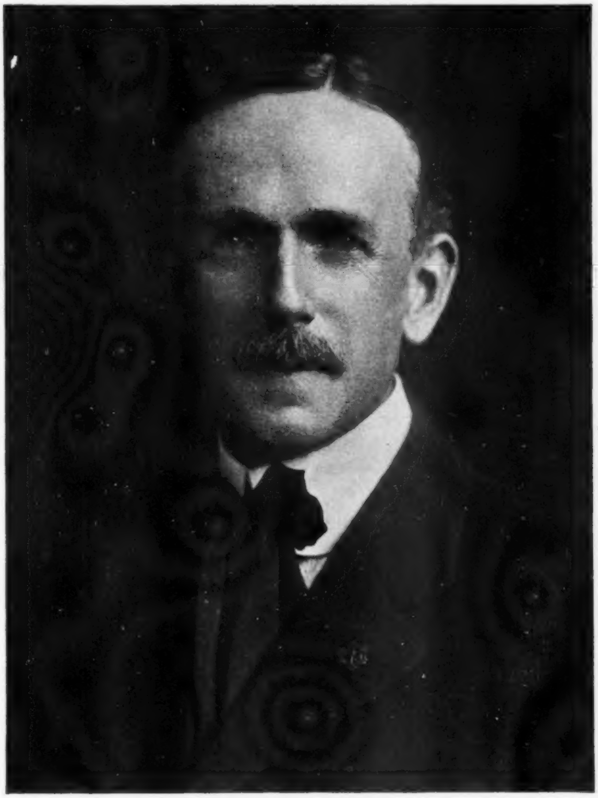
N. H. DARTON, HONORARY MEMBER

Dr. N. H. Darton, on whom the Association has recently conferred honorary membership, has, for more than half a century, contributed extensively to the literature and progress of American geology. His first geologic papers appeared in 1882, and the succeeding years, almost three score, have witnessed a procession from the press of his volumes, papers, and maps, numbering to the present about 220, on a wide variety of topics in geology and related fields.

Doctor Darton was born in New York, N. Y., December 17, 1865. In 1886 he entered the service of the Geological Survey; and, except for a short period (1910–13), when he was on the staff of the Bureau of Mines, he was employed almost continuously by the Geological Survey until 1936, when he was officially retired. Since 1936 he has, however, continued his geologic studies with his usual vigor and active interest. His field investigations and explorations have extended into more than half the states of the United States and into Mexico, Venezuela, and Cuba. In his work he has revealed a great diversity of interests, too great to enumerate here, but some measure of their character and scope may be gained from the subjects here mentioned: bibliography of North American geology; Appalachian geology; Newark rocks of New Jersey; artesian waters of South Dakota and Nebraska; geology of the Great Plains, Big Horn Mountains, Black Hills, Laramie Basin, Wyoming, Baja California, Cuicuilco, New Mexico, and Arizona; explosive gases in coal mines; underground waters and temperatures of the United States; the Northern Anthracite coal field of Pennsylvania; great Permian salt deposit; explosion craters; red beds and structures of New Mexico; the Grand Canyon of the Colorado; geologic and topographic maps of Arizona, South Dakota, Nebraska, New Mexico, and Texas.

The preparation by Doctor Darton of these state maps and numerous

other maps and reports—some prepared jointly with other workers—constitutes a remarkable record of achievement. Among these reports are 28 folios of the Geological Survey—far more than have been prepared by any other author; and among the publications of a popular nature are guidebooks of the Santa Fe and Southern Pacific routes (*Geological Survey Bulletins 613 and 845*, respectively), and the beautifully illustrated pamphlet, *Story of the*



N. H. DARTON

Grand Canyon (printed in 1917 by Fred Harvey), which has reached the 16th edition. Doctor Darton was the first to prepare a comprehensive bibliography of North American geology (*Geological Survey Bulletins 44, 75, 91, 99, and 127*) and to compile records of deep borings (*Geological Survey Water-Supply Papers 57 and 61*) and geothermal data (*Geological Survey Bulletin 701*) for the United States.

He takes an active interest and has been honored by membership in

many scientific societies, both in the United States and in other countries; he is an original fellow of the Geological Society of America which celebrates its 50th anniversary in New York in December, 1938, and is a charter member of the Society of Economic Geologists. In recognition of his explorations in southwestern United States and Mexico, the American Geographical Society presented to him in 1930 the Daly gold medal; and the University of Arizona conferred upon him in 1922 the degree of Doctor of Science.

Doctor Darton's elevation to honorary membership in the American Association of Petroleum Geologists is an especially fitting and appropriate recognition of his long and distinguished career in American geology—a career that has been helpful to and appreciated by the petroleum industry.

HUGH D. MISER

WASHINGTON, D. C.
May, 1938

ANDREW COWPER LAWSON, HONORARY MEMBER

Andrew Cowper Lawson, professor-emeritus, Department of Geology and Mineralogy of the University of California, was elected to honorary membership in the Association in December, 1937. He had been an active member since 1927. Unswerving service to the cause of the earth sciences has characterized the venerable career of this scholarly man whose name is now added to the select list of those who are recognized as having made conspicuous contributions to petroleum geology.

Born in Anstruther, Scotland, July 25, 1861, young Lawson sought the freedom and adventure of the west. His early manhood was spent in southern Canada where his fiery spirit and abundant energy found unlimited fields for functioning. By 1883 Andrew C. Lawson had won the Bachelor of Arts degree in the University of Toronto to be followed by the Master's degree in 1885. His doctorate was bestowed by Johns Hopkins University in his 28th year. During the period of his college training, and for 2 years thereafter, Lawson was a member of the Geological Survey of Canada. His early geological experience was gained in the trackless wilderness of Ontario and Manitoba. Enlightening contributions to pre-Cambrian geology, which have flowed from his facile pen down through the years, are largely based on observations made during his connection with the Canadian Survey.

The year 1899 was an important one in the annals of Andrew Lawson. Returning as one of the Canadian delegates to the International Geological Congress in London, he was made a Fellow of the Geological Society of America in May; in November he was united in marriage with Ludovika von Jantsch of Brünn, Moravia.

In 1890 Lawson was chosen as professor of geology and mineralogy at the University of California where he was daily associated with that beloved philosopher, naturalist, and renowned geologist, Joseph Le Conte, of sacred memory, who was then nearing the close of his benign career. Departmental and administrative duties fell to the new professor and it was not long until he became titular head of the department. The present strong department of geology and mineralogy of the University of California is largely the product of the labors of Andrew C. Lawson.

Upon his arrival in Berkeley Professor Lawson's alert mind was at once directed toward the multitudinous problems in California geology which were

manifest on every hand. His solutions for many of these problems constitute contributions to the geologic literature of the Pacific Coast, and of science in general, which are gems of logic, powerful in expression, beautiful in their simplicity and directness.

During his tenure of the chair of geology four sons were born to Professor Lawson. Surviving the mother, who died in 1929, are two of the four sons.

Andrew C. Lawson

Professor Lawson retired in 1928. During his 38 years of service in the educational field he attended as a delegate the International Geological Congresses in St. Petersburg in 1897, in Toronto in 1913, and in Madrid in 1926. He acted as chairman of the California Earthquake Investigation Commission in 1906; was president of the Seismological Society of America in 1909–10; served as chairman of the Division of Geology and Geography of the National

Research Council in 1923; and was president of the Geological Society of America in 1926. He holds membership in the Society of Economic Geologists, the American Association for the Advancement of Science, the American Academy of Arts and Sciences, the American Institute of Mining and Metallurgical Engineers, the National Academy of Sciences, the American Philosophical Society, and the American Association of Petroleum Geologists.

Andrew C. Lawson is outstanding among American men of science. Clear in his thinking, a foe to all enemies of truth with particular emphasis laid on demolishing sham and hypocrisy, firm in his convictions, strong in his beliefs, he is feared in argument and revered in counsel. His contributions to science are found not alone in his formidable list of published titles but also in the minds of the several generations of geologists who have begun their careers under his vehement guidance. To these and many others he is affectionately known as "the King."

Retirement was not recognized by Professor Lawson as a signal to cease firing. His zeal for research, ever a dominant factor in his makeup, was now given greater freedom for expression. He travelled extensively and roamed at will in the realm of geologic thought. His publications during this period are perhaps the best in his lengthy bibliography. Three years after relinquishing active duty at the University Professor Lawson was happily married to Isabel R. Collins; their home is maintained in Berkeley.

C. L. Moody

Shreveport, Louisiana
August 5, 1938

MID-YEAR MEETING, EL PASO, TEXAS SEPTEMBER 27–OCTOBER 2, 1938

The mid-year meeting of the Association will be held in El Paso, Texas, September 27–October 2, under the sponsorship of the West Texas Geological Society of Midland. El Paso may be reached by several railroads, two air lines, and numerous paved automobile highways.

Pre- and post-convention field trips will be held on September 27 and 28 and October 1 and 2, covering the most interesting geology of the area, including parts of one of the most complete Upper Paleozoic sections and, in particular, the most complete marine Permian section in the world.

Technical sessions will be held in the ballroom of the Cortez, convention headquarters hotel, on September 29 and 30.

The program given herewith is subject to change. Further information may be obtained from the chairman of the convention committees.

General chairman: Berte R. Haigh, University Lands, Midland
Assistant general chairman, in charge of A.A.P.G. affairs: Cary P. Butcher, Tide Water Associated Oil Company, Midland
Assistant general chairman, in charge of West Texas Geological Society affairs: H. A. Hemphill, Magnolia Petroleum Company, Midland
Technical program: Ronald K. DeFord, Argo Oil Corporation, Midland
Field trips: John Emery Adams, Standard Oil Company of Texas, Midland
Transportation: Vaughn C. Maley, Humble Oil and Refining Company, Midland
Reception: Fred H. Wilcox, Magnolia Petroleum Company, Midland
Entertainment: Paul F. Osborne, Tide Water Associated Oil Company, Midland
Hotel arrangements: Georges Vorbe, Midland
Golf: J. N. Gregory, Midland
Ladies entertainment: Mrs. Maurice Schwartz and Mrs. Paul F. Osborne
Finance: W. D. Anderson, Amerada Petroleum Corporation, Midland
Publicity: James FitzGerald, Jr., Skelly Oil Company, Midland

PRELIMINARY OUTLINE OF MID-YEAR PROGRAM

EL PASO, SEPTEMBER 27–OCTOBER 2 (OR 3)

(A) PRE-CONVENTION FIELD TRIPS

Trip a. Leave El Paso, Tuesday A.M., September 27, and return to El Paso, Wednesday P.M., September 28

Trip b. Leave Alpine, Texas, Tuesday A.M., September 27, and arrive El Paso, Wednesday P.M., September 28

(B) TECHNICAL SESSION

Wednesday, September 28

8:00 P.M.–10:00 P.M. Registration

Thursday, September 29

8:00 A.M.–10:00 A.M. Registration

10:00 A.M.–12:00 Noon, 1:30 P.M.– 4:30 P.M. Technical session

7:00 P.M. Dinner-dance at Tivoli

Ladies' entertainment throughout day as arranged by Mrs. Schwartz and Mrs. Osborne

Friday, September 30

9:00 A.M.–12:00 Noon, 1:30 P.M.– 4:30 P.M. Technical session

5:00 P.M.– 9:00 P.M. Barbecue—McKelligan Canyon (stag)

Ladies' entertainment throughout day as arranged by Mrs. Schwartz and Mrs. Osborne

11:00 P.M. Entrain for trip to Chihuahua

(C) POST-CONVENTION FIELD TRIPS

Trip a. (Chihuahua) Leave El Paso, 11:00 P.M., Friday, September 30 Leave Chihuahua at such time, Saturday night, as to arrive at El Paso by noon, Sunday, October 2

Trip b. Leave El Paso, 7:00 A.M., Saturday, October 1. Arrive Carlsbad, New Mexico, Saturday evening. Spend Sunday, October 2, in vicinity of Carlsbad. Leave Carlsbad, 7:00 A.M., Monday, October 3, make trip through New Mexico and West Texas oil fields and end trip at Monahans or Midland, Monday evening

Trip c. Leave El Paso, 7:00 A.M., Saturday
Arrive Marfa, Texas (via Van Horn, Fort Davis, and Alpine) Saturday night
Leave Marfa, 7:00 A.M., Sunday, spend day in Green Valley area and end trip at Alpine, Sunday evening

BRIEF DESCRIPTIVE OUTLINE OF PROPOSED FIELD TRIPS

PRE-CONVENTION

Trip a. Leave El Paso at 7:00 A.M., Tuesday, September 27, traveling northward into New Mexico, studying Paleozoic section of Franklin, Jarilla, and Sacramento mountains, visiting gypsum sands of White Sands National Monument, and arriving at Alamogordo, New Mexico, that evening
Wednesday, September 28. Leave Alamogordo at 7:00 A.M., traverse Tularosa Basin, cross San Andres Mountain via Rhodes Canyon, thence across Jornada del Muerto to Elephant Butte Dam, and down Rio Grande to El Paso, arriving about 7:00 P.M.

Trip b. All persons taking this trip will arrange to arrive at Alpine, Texas (on the Southern Pacific R. R., T. & N. O. Division, 225 miles east of El Paso) by or during the night of September 26
Tuesday, September 27, leave Alpine at 7:00 A.M. and spend entire day in Glass Mountain area, studying young Paleozoic section, returning to Alpine that night
Wednesday, September 28, leave same place at 7:00 A.M. and spend approximately one-half day in the older Paleozoic area of Marathon Region, returning to Alpine to entrain for El Paso at 2:30 P.M. or to drive to El Paso (if you have automobile transportation), reaching El Paso at about 7:00 P.M., M.S.T.

POST-CONVENTION

Trip a. The city of Chihuahua, Mexico, and near-by mining district. Leave El Paso via National Railways of Mexico at 11:00 P.M., Friday, September 30; arrive Chihuahua early Saturday morning; spend day visiting smelters and mining districts in Chihuahua area. Entertainment furnished by Chihuahua Chamber of Commerce, Saturday evening. Leave Chihuahua sometime Saturday night and arrive at El Paso about noon Sunday, October 2

Geologists making Chihuahua trip and wishing to take oil-field trip on Monday may arrange to meet this group at Carlsbad, Sunday night. Bus transportation from El Paso to Carlsbad will be available Sunday afternoon

Trip b. Leave El Paso, Saturday, October 1, at 7:00 A.M., travel via Hueco and Guadalupe Mountains to Carlsbad, New Mexico, covering Paleozoic section; spend Sunday in vicinity of Carlsbad, visiting Caverns, potash mines, and Capitan Reef formation in Dark Canyon

Leave Carlsbad, 7:00 A.M., Monday, October 3, and traverse oil fields of southeastern New Mexico and West Texas, arriving at either Monahans or Midland (T. & P. Ry.), Monday evening

Trip c. Leave El Paso, 7:00 A.M., Saturday, October 1, visiting Jurassic formation in Malone Mountains and Neocomian Cretaceous in the Quitman Mountains; thence through Davis Mountains (Eocene volcanics) to Marfa, where will spend Saturday night

Leave Marfa, 7:00 A.M., Sunday, October 2, and spend day visiting volcanic section in Big Bend area, arriving at Alpine (S. P. Ry.), Sunday night

TECHNICAL PAPERS OF MID-YEAR PROGRAM

(Except for first two papers, chronological order of presentation has not been definitely arranged.)

ED. W. OWEN (L. H. Wentz, Oil Division, San Antonio): An introductory paper covering the area and problems that will be discussed in detail throughout remainder of the program. 30 min.

JAMES FITZGERALD, JR. and W. C. FRITZ (Skelly Oil Co., Midland), E. HAZEN WOODS (Sinclair-Prarie Oil Co., Midland), and ROBERT I. DICKEY (Stanolind Oil and Gas Co., Midland): Cross Sections of Central Basin Platform. 30 min.

M. G. CHENEY (consulting geologist, Coleman, Tex.): Geology of North-Central and Central Texas. 45 min.

LOUIS V. OLSON (American Smelting and Refining Co., El Paso): Aerial Photography for Geological Exploration. 32 min.

CARY P. BUTCHER (Tide Water Associated Oil Co., Midland): The Guadalupe Mountains as They Look to the Aerial Geologist. 20 min.

RONALD K. DEFORD (Argo Oil Corp., Midland), GEORGE D. RIGGS and NEIL H. WILLS (consulting geologists, Carlsbad, New Mex.): Surface and Subsurface Formations, Eddy County, New Mexico. 32 min.

GEORGE A. KROENLEIN (consulting geologist, Lovington, New Mex.): Salt and Potash in the Upper Castile Formation of Southeast New Mexico. 32 min.

PHILIP B. KING (U. S. Geological Survey): Relation of Permian Sedimentation to Tectonics in the Guadalupe Mountain Region. 32 min.

E. RUSSELL LLOYD (consulting geologist, Midland): Theory of Reef Barriers. 32 min.

LINCOLN R. PAGE (University of Colorado, Boulder): Stratigraphy, Eastern Midland Basin, Texas. 20 min.

TAYLOR COLE (University Lands, Midland): Notes on the Black Shale Basin of West Texas. 25 min.

FRANK E. LEWIS (consulting geologist, Midland): Stratigraphy of the Upper and Middle Permian of West Texas and Eastern New Mexico. 50 min.

JOHN W. SKINNER (Humble Oil and Refining Co., Midland): Upper Paleozoic Section of the Chinati Mountains, Presidio County, Texas. 25 min.

E. H. SELLARDS (Bureau of Economic Geology, Austin): Early Paleozoic Formations in Texas. 30 min.

LLOYD A. NELSON (College of Mines and Metallurgy, El Paso): Paleozoic Stratigraphy of the Franklin Mountains of West Texas. 30 min.

CLAUDE E. NEEDHAM (New Mexico School of Mines, Socorro): Correlation of the Pennsylvanian Rocks of New Mexico. 25 min.
MORRIS A. ELMS (Phillips Drilling Co., San Antonio): Volcanics of the Buck Hill Quadrangle, Brewster County, Texas. 25 min.
W. D. ANDERSON and JAMES R. DAY (Amerada Petroleum Corp., Midland): Monument Field, Lea County, Mexico. 20 min.
H. G. WALTER (The Texas Co., Hobbs, New Mex.): Vacuum Field, Lea County, New Mexico. 20 min.
SAM C. GIESEY and FRANK F. FULK (Stanolind Oil and Gas Co., Midland): North Cowden Field, Ector County, Texas. 20 min.
E. H. POWERS (Gulf Oil Corp., Midland): Sandhills Field, Crane County, Texas. 20 min.

MID-YEAR MEETING HOTELS

All those planning to attend the meeting should make reservations directly with the hotel of their choice, as soon as possible. *Confirmation should be requested*, and *should be presented at the desk at time of registration*, thereby eliminating confusion and misunderstandings relative to accommodations.

HOTEL CORTEZ (Headquarters)

300 rooms, all outside and all with bath; partly air-conditioned

Single	$2.00–$ 4.50
Double	4.00– 10.00
Suites	7.00– 20.00

HOTEL PASO DEL NORTE (two blocks from Headquarters)

250 rooms, all outside and all with bath; partly air-conditioned

Single	$2.50–$ 6.00
Double	4.00– 9.00
Suites	8.00– 35.00

HILTON HOTEL (one block from Headquarters)

300 rooms, all outside and all with bath; partly air-conditioned

Single	$2.50–$ 4.50
Double	4.00– 10.50
Suites	6.00– 8.00

KNOX HOTEL (four blocks from Headquarters)

100 rooms; completely air-conditioned

Single, with bath	$2.00–$2.50
Double, with bath	2.50– 3.50
Single, without bath	1.50
Double, without bath	2.00

GATEWAY HOTEL (three blocks from Headquarters)

110 rooms, all with bath

Single	$1.50–$2.00
Double	2.50– 4.00

HOTEL MCCOY (one block from Headquarters)

100 rooms

Single, with bath	$2.00–$2.50
Double, with bath	2.50– 3.50
Suites, with bath	4.00– 7.00
Single, without bath	1.00– 1.50
Double, without bath	1.50– 2.00

HOTEL LOCKIE (one block from Headquarters)

110 rooms

Single, with bath	$1.50
Double, with bath	2.00–2.50
Single, without bath	1.00
Double, without bath	1.50

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

Donald C. Barton, *chairman*, Houston, Texas
H. B. Fuqua, Fort Worth, Texas
Ira H. Cram, *secretary*, Tulsa, Oklahoma
Harold W. Hoots, Los Angeles, California
W. A. Ver Wiebe, Wichita, Kansas

BUSINESS COMMITTEE

Carl C. Anderson (1940)
Arthur A. Baker (1940)
Donald C. Barton (1940)
William A. Baker (1939)
Orval L. Brace (1939)
Cary P. Butcher (1939)
Frederic A. Bush (1939)
Harold S. Cave (1939)
Robert W. Clark (1939)
Ira H. Cram (1939)
A. F. Crider (1939)
A. Arthur Curtice (1939)
H. B. Fuqua (1939)
Benjamin F. Hake (1939)
V. G. Hill (1939)
Harold W. Hoots (1939)
John F. Hosterman (1939)
H. V. Howe (1939)
J. Harlan Johnson (1939)
Edward A. Koester (1939)
P. W. McFarland (1940)
David Perry Olcott (1939)
Virgil Pettigrew (1940)
R. B. Rutledge (1939)
R. F. Schoolfield (1939)
E. H. Sellards (1939)
Fred P. Shayes (1939)
S. E. Slipper (1939)
Homer J. Steiny (1939)
W. T. Thom, Jr. (1939)
Wallace C. Thompson (1940)
James A. Tong (1939)
Walter A. Ver Wiebe (1939)
Andrew C. Wright (1939)

RESEARCH COMMITTEE

A. I. Levorsen (1941), *chairman*, 221 Woodward Boulevard, Tulsa, Oklahoma
Harold W. Hoots (1939), *vice-chairman*, Richfield Oil Corporation, Los Angeles, California

Donald C. Barton (1939)
Glenn H. Bowes (1939)
W. L. Goldston (1939)
W. C. Spooner (1939)
Parker D. Trask (1939)
Maurice M. Albertson (1940)
Rollin Eckis (1940)
William E. Hubbard (1940)
John C. Karcher (1940)
Norman L. Thomas (1940)
N. W. Bass (1941)
E. Wayne Galliher (1941)
H. Hlauschek (1941)
Walter Kauenhowen (1941)
Ben H. Parker (1941)
Wendell P. Rand (1941)

REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

Frederic H. Lahee (1940)

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

John G. Bartram, *chairman*, Stanolind Oil and Gas Company, Casper, Wyoming

M. G. Cheney
Alexander Deussen
Glenn S. Dille
B. F. Hake
G. D. Hanna
M. C. Israelsky
A. I. Levorsen
C. L. Moody
R. C. Moore
Ed. W. Owen
J. R. Reeves
Allen C. Tester
W. A. Thomas

TRUSTEES OF REVOLVING PUBLICATION FUND

J. V. Howell (1939)
Ralph D. Reed (1940)
Ben F. Hake (1941)

TRUSTEES OF RESEARCH FUND

Alex W. McCoy (1939)
Robert J. Riggs (1940)
A. A. Baker (1941)

FINANCE COMMITTEE

W. B. Heroy (1939)
E. DeGolyer (1940)
Wallace E. Pratt (1941)

COMMITTEE ON APPLICATIONS OF GEOLOGY

Frank Rinker Clark, *chairman*, Box 981, Tulsa, Oklahoma

Olin G. Bell
Arthur E. Brainerd
Ira Otho Brown
Hal P. Bybee
Carey Croneis
Robert H. Dott
H. S. McQueen
C. R. McKnight
S. E. Slipper
E. K. Soper
Earl A. Trager

COMMITTEE FOR PUBLICATION

Frederic H. Lahee, *chairman*, Box 2880, Dallas, Texas

Carl C. Anderson
Walter R. Berger
Charles Brewer, Jr.
T. C. Craig
George R. Downs
James Terry Duce
James FitzGerald, Jr.
Harold W. Hoots
J. Harlan Johnson
Edward A. Koester
Chas. H. Lavington
A. I. Levorsen
A. M. Lloyd
W. A. Maley
Phillip F. Martyn
Graham B. Moody
Ed. W. Owen
R. E. Rettger
J. T. Richards
Theron Wasson
A. W. Weeks
A. C. Wright

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 1127-1128.

Memorial

IVAN VINCENT BENTZ
(1896–1938)

Ivan Vincent Bentz died on June 2, 1938, in the U. S. Marine Hospital at Galveston, Texas. He had been operated on for gallstones two weeks before and was apparently recovering. On the day of his death, he arose, took a few steps, and dropped dead from a heart attack.

Ivan Bentz was born on May 25, 1896, in University Place, Nebraska. He graduated from Fairfield, Nebraska High School, attended Nebraska Wesleyan one year, and graduated from the University of Nebraska in 1924.

He was a World War veteran, having first served with the 355th Regiment, a Nebraska unit, later with Fire-Guard Company 321, at Governors Island, New York, and was a member of the Hearney Nebraska Post of the American Legion.

Ivan Bentz was married, January 12, 1919, to Marie Weyenberg of Fairfield, Nebraska, who survives him with their four children, George Vincent, Warren Worthington, Margaret Lorn, and Marion Francis.

His funeral services were held, June 7, at Fairfield, Nebraska. He was accorded military honors by the American Legion.

Ivan Bentz had served the Indian Territory Illuminating Oil Company, the Transcontinental Oil Company, the Amerada Petroleum Corporation, and the Gulf Production Company as a geologist in Oklahoma, Kansas, Texas, and Louisiana for many years. During the past several years he had been a consultant in Texas and Louisiana.

He was a member of Sigma Gamma Epsilon and a former member of The American Association of Petroleum Geologists and the San Antonio Geological Society.

Ivan Bentz had a brilliant mind, but had suffered a severe handicap during his geological career because of ill health. He had many friends in the geological fraternity, to whom he was affectionately known as "Trotsky." He had a strong desire to live, and was ambitious to succeed in his profession. To his friends his death is a shock, particularly because of his youth and because his career is ended when it seemed that he might regain his health.

Our deepest sympathies are extended to his family. They have lost a husband and father; we have lost a friend.

L. B. SNIDER

SAN ANTONIO, TEXAS
July, 1938

LLOYD IRVIN YEAGER
(1900–1938)

Lloyd Irvin Yeager died suddenly on July 13, 1938, in Wichita, Kansas, after he had apparently recovered from a serious illness suffered 18 months previously. His death was the result of a liver ailment.

He is survived by his wife, Betty Snider Yeager, and daughter Evelyn, of Wichita, Kansas, and his mother, Mrs. Lida B. Yeager, of Milroy, Pennsylvania.

Yeager was born in Milroy, Pennsylvania, on August 12, 1900, and attended the public schools there. After graduating from Pennsylvania State College in 1924, with a B.S. degree in mining geology, he immediately became affiliated with the Empire Companies as a junior engineer. His career as a geologist for that company led him through various positions in many areas in Oklahoma and Kansas until he became district geologist at Wichita, Kansas, in 1929. Yeager held this position until his serious illness in the latter part of 1936. Upon his apparent recovery, he was transferred in September, 1937, to Roswell, New Mexico. In January, 1938, he resigned his position with the Cities Service Oil Company and returned to Wichita to enter the consulting field, in which he was active until his death.

Yeager's pleasant personality and amiable disposition, coupled with a keen sense of humor and understanding, made for him a host of friends to whom his sudden passing came as a shock. The geological profession has suffered a definite loss for he had accumulated a fund of knowledge in his comparatively few years of work and was held in high esteem by operators and associates alike.

ARTHUR K. WILHELM

BARTLESVILLE, OKLAHOMA
July 27, 1938

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 22, NO. 8 (AUGUST, 1938), PP. 1129-1132

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

KURT H. DE COUSSER, geologist with the Socony Vacuum Oil Company, Lansing, Michigan, is president of the Michigan Scouts Association.

H. W. WEDDLE has recently been transferred from the Standard Oil Company of Texas, at Houston, to the Standard Oil Company of California at Bakersfield.

I. W. JONES, geologist for the Canadian Bureau of Mines, is head of one of the three geological parties which are studying the oil resources of the Gaspé Peninsula, Quebec.

FRANCIS BAKER LANEY, head of the department of geology at the University of Idaho since 1920, died April 24, at the age of 63.

EDWARD H. ROTT, JR., resigned as geologist and hydrologist for the Soil Conservation Service to accept a position with the Richmond Petroleum Company at Ibague, Colombia.

THOMAS HENRY DIGGS LA TOUCHE, member of the Geological Survey of India, died March 30, at the age of 82. He published several indexes and bibliographies, and his greatest work was the survey of the Northern Shan States of Burma.

OSCAR E. WALTON, Atlantic Refining Company, has been transferred from Corpus Christi to Dallas, Texas. He is succeeded as district geologist at Corpus Christi by OWEN WOOD.

HARVEY HARDISON, Standard Oil Company of Texas, Midland, has been transferred to Dallas, where he will serve as chief engineer.

JAMES H. MCQUIRT, assistant State geologist of Louisiana, is preparing a report on the Tertiary Bryozoa of Louisiana, intended to be helpful in correlating the formations of the Gulf Coastal Plain.

JUSTIN BLAKE, of the Louisiana State Geological Survey, is conducting field and laboratory studies for a report of Natchitoches Parish. The Angelina-Caldwell flexure crosses the parish.

J. N. TROXELL, The Texas Company, has been transferred from Tulsa, Oklahoma, as division geologist of Oklahoma-Kansas-Kentucky, to geologist in the office of production manager at the company's headquarters in Houston, Texas.

WILLIAM H. CURRY, Wellington Oil Company, recently discussed the Cretaceous stratigraphy of Maverick County and the Chittim anticline at a meeting of the South Texas Geological Society.

H. H. ARNOLD, The Texas Company, has succeeded J. N. Troxell as district geologist at Tulsa.

M. H. Steig, formerly with the Shell Petroleum Company, Houston, is now with the Phillips Petroleum Company, 521 Esperson Building, Houston.

Harry H. Kuck, Jr., of Savannah, Georgia, who received the degree of Bachelor of Arts, in geology, from Cornell University this year, is employed by the Sun Oil Company at Beaumont, Texas.

E. V. Whitwell recently resigned his position as chief geologist of the Carter Oil Company to accept a position with the Bay Oil Corporation, Tulsa, Oklahoma, and Shreveport, Louisiana.

Clyde M. Becker, consulting geologist of Chickasha, Oklahoma, died on July 19, as the result of a cerebral hemorrhage following an illness of several months.

Charles O. Hansard, Jr., is now with the Ohio Oil Company with headquarters at Houston, Texas.

W. Ross Keyte, formerly with the Forest Development Corporation at Abilene, Texas, has recently opened a consulting office at 311 Bennett Building, Colorado Springs, Colorado.

Ben F. Hake, Gulf Refining Company, has been transferred to Indianapolis, Indiana, where he will act as chief of the company's new divisional office. Michigan, Indiana, Illinois, and Kentucky are included in Hake's new district. Jed Mabius succeeds Hake as resident Michigan geologist at Saginaw.

Phillip Maverick, consulting geologist, San Angelo, Texas, is moving to Fort Worth to join the technical staff of the U. S. Securities and Exchange Commission.

Robert L. Jones, Cities Service Oil Company, Tyler, Texas, has been transferred to Houston as geologist for the Gulf Coast district. He succeeds Elton Rhine who recently resigned to join the Phillips Petroleum Company.

Maurice R. Teis, formerly with E. H. Moore, Inc., has been appointed chief geologist of the Home-Stake Oil and Gas Company.

Kenneth K. Landes, University of Kansas, officiated at the installation of the thirty-second chapter of Sigma Gamma Epsilon at Augustana College, Rock Island, Illinois, on June 3. His address was entitled "The Geology of Chugach Range, Alaska."

A. E. McKay, Atlantic Refining Company, formerly at Midland, Texas, has been transferred to Havana, Cuba, and may be addressed at 410 Edificio La Metropolitona.

Louis C. Sass has recently been transferred from the operations of the Mene Grande Oil Company in eastern Venezuela to a position with the Kuwait Oil Company, in Arabia. He may be addressed in care of Kuwait Oil Company, Kuwait, Persian Gulf.

Henry Emmett Gross, formerly assistant professor of petroleum engineering at the University of Oklahoma, is now associate professor of petro-

leum engineering at Texas Agricultural and Mechanical College, College Station, Texas.

LLOYD I. YEAGER, Trans-Western Oil Company, died at his home in Wichita, Kansas, on July 13.

ALEXANDER DEUSSEN, Houston, Texas, FRED A. GILLETTE, and MARTHA LATHAM have organized the East Texas Oil Company, Incorporated. Deussen is the president of the new company.

E. R. ATWILL, Union Oil Company of California, has been made special research geologist at Los Angeles. Atwill was formerly division geologist at Bakersfield, and is succeeded by W. LAYTON STANTON.

F. C. SEALEY, The Texas Company, formerly manager of producing operations in California, has been appointed to a new position in New York. He is succeeded in the California office by JAMES T. WOOD, JR.

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

(Continued from page 1118)

FOR ACTIVE MEMBERSHIP

John Head Crowell, Houston, Tex.
George S. Buchanan, A. L. Smith, Elisabeth Stiles
Malvern Edward Hoover, Glendale, Calif.
William S. W. Kew, Louis N. Waterfall, Chester Cassel
Arland Irving Innes, Tulsa, Okla.
Andrew Gilmour, J. F. Hosterman, A. R. Denison
George David Lindberg, Toledo, Ohio
P. Hastings Keller, R. B. Newcombe, William A. Thomas
Don D. Montgomery, Ada, Okla.
D. A. McGee, R. H. Lynn, D. C. Nufer
Montague Ongley, Madang, New Guinea
Harve Loomis, W. G. Argabrite, Charles F. Bowen
Arthur Lawrence Payne, Trinidad, B. W. I.
H. G. Kugler, E. C. Scott, G. H. Scott

FOR ASSOCIATE MEMBERSHIP

Charles Samuel Agey, Wichita, Kan.
Dollie Radler Hall, A. R. Denison, Robert L. Cassingham
Horace Richard Blank, Waco, Tex.
Fred M. Bullard, E. H. Sellards, Watson H. Monroe
Mac Otts Boring, Jr., Fort Worth, Tex.
B. E. Thompson, J. B. Lovejoy, Paul A. Grant
Sam Russel Casey, Jr., Houston, Tex.
Carleton D. Speed, Jr., Lon D. Cartwright, Jr., Kenneth H. Ferguson
Bernard Belden Colley, Palo Alto, Calif.
A. O. Woodford, F. G. Tickell, Eliot Blackwelder
Daniel John Jones, Bartlesville, Okla.
Charles E. Decker, V. E. Monnett, T. E. Weirich

Gid Calmese Mayfield, Dallas, Tex.
Lewis W. MacNaughton, Robert H. Cuyler, Albert E. Oldham
Wright Daniel McEachin, Tulsa, Okla.
Frederic A. Bush, R. M. Gawthrop, A. N. Murray
Boyd Ferguson Murphy, Tyler, Tex.
J. F. Hosterman, A. R. Denison, Dollie Radler Hall
Fred Franklin Yockstick, Fort Worth, Tex.
P. C. Dean, E. H. Sellards, Roy A. Reynolds

FOR TRANSFER TO ACTIVE MEMBERSHIP

Willis C. Blackburn, Crowley, La.
L. P. Teas, D. P. Carlton, L. T. Barrow
Charles Edward Bradford, Hays, Kan.
H. F. Davies, Charles S. Lavington, Charles E. Erdmann
H. Travis Brown, Oklahoma City, Okla.
L. R. McFarland, W. W. Clawson, John E. Van Dall
Robert S. Christie, Fort Worth, Tex.
C. V. Millkina, A. R. Denison, J. F. Hosterman
Garner Conrad Clark, Amarillo, Tex.
William J. Nolte, A. L. Ackers, Vernon E. Autry
Charles La Verne Decker, Houston, Tex.
John C. Myers, W. Grant Blanchard, James W. Kisling, Jr.
Glenn Charles Ferguson, Bakersfield, Calif.
Rouse Simmons, Stanley G. Wissler, A. A. Curtice
Joseph Nalle Gregory, San Angelo, Tex.
Lon D. Cartwright, Jr., Hal P. Bybee, Cary P. Butcher
Leo J. Gude, Oklahoma City, Okla.
E. A. Paschal, Dean M. Stacy, Wesley G. Gish
Hillord Hinson, Houston, Tex.
P. B. Leavenworth, James C. Montgomery, R. A. Stamey
Samuel Henry Houston, Jr., Corpus Christi, Tex.
L. T. Barrow, L. P. Teas, L. F. McCollum
Edward L. Howard, Tyler, Tex.
George W. Pirtle, E. B. Wilson, Wallace C. Thompson
R. Lee Hunter, Ponca City, Okla.
W. Baxter Boyd, Everett C. Parker, S. K. Clark
Edward V. Winterer, Bakersfield, Calif.
W. D. Kleinpell, O. F. Kotick, W. A. English

NEW YORK

FREDERICK G. CLAPP
Consulting Geologist

50 Church Street
NEW YORK

BROKAW, DIXON & McKEE
Geologists *Engineers*
OIL—NATURAL GAS
Examinations, Reports, Appraisals
Estimates of Reserves

120 Broadway, New York
Gulf Building, Houston

A. H. GARNER
Geologist *Engineer*
PETROLEUM
NATURAL GAS

120 Broadway New York, N.Y.

OHIO

JOHN L. RICH
Geologist

Specializing in extension of "shoestring" pools

University of Cincinnati
Cincinnati, Ohio

OKLAHOMA

ELFRED BECK
Geologist

525 National Bank of Tulsa Building
TULSA OKLAHOMA

GINTER LABORATORY
CORE ANALYSES
Permeability
Porosity
Reserves

R. L. GINTER
Owner

118 West Cameron, Tulsa

MALVIN G. HOFFMAN
Geologist

Midco Oil Corporation
Midco Building
TULSA, OKLAHOMA

R. W. Laughlin L. D. Simmons

WELL ELEVATIONS
Oklahoma, Kansas, Texas, and New Mexico

LAUGHLIN-SIMMONS & CO.
605 Oklahoma Gas Building
TULSA OKLAHOMA

MID-CONTINENT TORSION BALANCE SURVEYS
SEISMIC AND GRAVITY INTERPRETATIONS

KLAUS EXPLORATION COMPANY
H. KLAUS
Geologist and Geophysicist

Broadway Tower, Enid, Okla.
Benson Building, Lubbock, Texas

A. I. LEVORSEN
Petroleum Geologist

221 Woodward Boulevard
TULSA OKLAHOMA

DIRECTORY OF GEOLOGICAL AND GEOPHYSICAL SOCIETIES

For Space Apply to A.A.P.G. Headquarters
Box 979, Tulsa, Oklahoma

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS

DENVER, COLORADO

President - - - - - Charles S. Lavington
Continental Oil Company
1st Vice-President - - Warren O. Thompson
985 Gilbert Street, Boulder
2nd Vice-President - - - David B. Miller
1336 Gaylord Street
Secretary-Treasurer - - - - - - Ninetta Davis
224 U. S. Customs Building

Dinner meetings, first and third Mondays of each month, 6:15 P.M., Auditorium Hotel.

KANSAS

KANSAS GEOLOGICAL SOCIETY

WICHITA, KANSAS

President - - - - - - - - Edward A. Koester
Darby Petroleum Corporation
Vice-President - - - - - Glen C. Woolley
Transwestern Oil Company
Secretary-Treasurer - - Forrest E. Wimbish
517 North Chautauqua
Member of Board - - - - - George H. Norton
Atlantic Refining Company

Regular Meetings: 7:30 P.M., Allis Hotel, first Tuesday of each month. Visitors cordially welcomed.
The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Building.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY

SHREVEPORT, LOUISIANA

President - - - - - - - B. W. Blanpied
Gulf Oil Corporation
Vice-President - - - - - E. B. Hutson
Standard Oil Company of Louisiana
Secretary-Treasurer - - - - J. D. Aimer
Arkansas-Louisiana Gas Company

Meets the first Friday of every month, 7:30 P.M., Civil Courts Room, Caddo Parish Court House. Special dinner meetings by announcement.

SOUTH LOUISIANA GEOLOGICAL SOCIETY

LAKE CHARLES, LOUISIANA

President - - - - - - - - - - J. F. Mahoney
Union Sulphur Co., Sulphur Mines, La.
Vice-President - - - - - - - - Dean F. Metts
Humble Oil & Refining Co., Crowley, La.
Secretary - - - - - - - - - W. R. Canada
Stanolind Oil and Gas Company
Treasurer - - - - - - - Baker Hoskins
Shell Petroleum Corporation

Meetings: First Monday at noon (12:00) and third Monday at 7:00 P.M. at Majestic Hotel. Visiting geologists are welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY

ARDMORE, OKLAHOMA

President - - - - - - Jerome M. Westheimer
Consulting Geologist
Vice-President - - - - - - - - - O. H. Hill
Shell Petroleum Corporation
Secretary-Treasurer - - - - - - - - J. P. Gill
Sinclair Prairie Oil Company
Chairman Program Committee - - Don L. Hyatt
Carter Oil Company, Dillard, Oklahoma

Meetings: First Tuesday of each month, from October to May, inclusive, at 7:30 P.M., Dornick Hills Country Club.

OKLAHOMA CITY GEOLOGICAL SOCIETY

OKLAHOMA CITY, OKLAHOMA

President - - - - - - - E. A. Paschal
Coline Oil Company
Vice-President - - - - - Dan O. Howard
Oklahoma Corporation Commission
Secretary-Treasurer - - - - - R. B. Curry
Carter Oil Company, 420 Colcord Building

Meetings: Second Monday, each month, 8:00 P.M., Magnolia Building. Luncheons: Every Monday, 12:15 P.M., Ninth Floor, Commerce Exchange Building.

OKLAHOMA

SHAWNEE GEOLOGICAL SOCIETY

SHAWNEE, OKLAHOMA

President - - - - - - - A. M. Meyer
Atlantic Refining Company

Vice-President - - - - - - V. G. Hill
Stanolind Oil and Gas Company

Secretary-Treasurer - - - J. Lawrence Muir
Amerada Petroleum Corporation

Meets the fourth Monday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

THE STRATIGRAPHIC SOCIETY OF TULSA

TULSA, OKLAHOMA

President - - - - - - - - - - L. H. Lukert
The Texas Company

Vice-President - - - - - - L. A. Johnston
Sunray Oil Company

Secretary-Treasurer - - Constance Leatherock
Tide Water Associated Oil Company

Meetings: Second and fourth Wednesdays, each month, from October to May, inclusive, at 8:00 P.M.

TULSA GEOLOGICAL SOCIETY

TULSA, OKLAHOMA

President - - - - - - - - - Robert J. Riggs
Stanolind Oil and Gas Company
1st Vice-President - - - - - - - N. W. Bass
United States Geological Survey
2nd Vice-President - - - - - Clark Millison
McBirney Building
Secretary-Treasurer - - - - - L. A. Johnston
Sunray Oil Company
Editor - - - - - - - - R. V. Hollingsworth
Shell Petroleum Corporation

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., fourth floor, Tulsa Building. Luncheons: Every Thursday, fourth floor, Tulsa Building.

TEXAS

DALLAS PETROLEUM GEOLOGISTS

DALLAS, TEXAS

President - - - - - Dilworth S. Hager
932 Liberty Building

Vice-President - - - - - R. E. Rettger
Sun Oil Company

Secretary-Treasurer - - - W. W. Clawson
Magnolia Petroleum Company

Meetings: Regular luncheons, first Monday of each month, 12:15 noon, Petroleum Club. Special night meetings by announcement.

EAST TEXAS GEOLOGICAL SOCIETY

TYLER, TEXAS

President - - - - - - Robert L. Jones
Cities Service Oil Company

Vice-President - - - - - - - - A. C. Wright
Shell Petroleum Corporation

Secretary-Treasurer - - - - - - C. L. Herold
Shell Petroleum Corporation

Meetings: Monthly and by call.

Luncheons: Every Friday, Cameron's Cafeteria.

FORT WORTH GEOLOGICAL SOCIETY

FORT WORTH, TEXAS

President - - - - - - - A. L. Ackers
Stanolind Oil and Gas Company

Vice-President - - - - Clarence E. Hyde
1715 W. T. Waggoner Building

Secretary-Treasurer - - Herbert H. Bradfield
The Texas Company

Meetings: Luncheon at noon, Worth Hotel, every Monday. Special meetings called by executive committee. Visiting geologists are welcome to all meetings.

HOUSTON GEOLOGICAL SOCIETY

HOUSTON, TEXAS

President - - - - - - - John C. Miller
The Texas Company

Vice-President - - - - - David Perry Olcott
Humble Oil and Refining Company

Secretary-Treasurer - - Lon D. Cartwright, Jr.
Skelly Oil Company

Regular meetings, every Thursday at noon (12:15) at the Houston Club. Frequent special meetings called by the executive committee. For any particulars pertaining to meetings call the secretary.

TEXAS

NORTH TEXAS GEOLOGICAL SOCIETY

WICHITA FALLS, TEXAS

President - - - - - - - A. W. Weeks
Box 82

Vice-President - - - - - Tom F. Petty
Humble Oil & Refining Company

Secretary-Treasurer - - - Paul E. M. Purcell
Shell Petroleum Corporation

Luncheons and evening programs will be announced.

WEST TEXAS GEOLOGICAL SOCIETY

SAN ANGELO AND MIDLAND, TEXAS

President - - - - - - - - H. A. Hemphill
Magnolia Petroleum Company, Midland

Vice-President - - - - - - W. D. Anderson
Amerada Petroleum Corporation, Midland

Secretary-Treasurer - - - - - - - W. C. Fritz
Skelly Oil Company, Midland

Meetings will be announced

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - F. M. Kannenstine
Kannenstine Laboratories, Houston, Texas
2011 Esperson Building

Vice-President - - - - - - - - W. T. Born
Geophysical Research Corporation
Tulsa, Oklahoma

Editor - - - - - - - M. M. Slotnick
Humble Oil & Refining Co., Houston, Texas

Secretary-Treasurer - - - - - - H. B. Peacock
Geophysical Service, Inc., Houston, Texas
825 Esperson Building

SOUTH TEXAS GEOLOGICAL SOCIETY

SAN ANTONIO AND CORPUS CHRISTI TEXAS

President - - - - - - - - W. A. Maley
Humble Oil and Refining Company, Corpus Christi

Vice-President - - - - - - W. W. McDonald
Arkansas Natural Gas Company, San Antonio

Secretary-Treasurer - - - - - - C. C. Miller
The Texas Company, Corpus Christi

Executive Committee - - - - - D. G. Barnett

Meetings: Third Friday of each month at 8 P.M. at the Petroleum Club. Luncheons every Monday noon at Petroleum Club, Alamo National Building, San Antonio, and at Plaza Hotel, Corpus Christi.

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY

CHARLESTON, WEST VIRGINIA
P.O. Box 1435

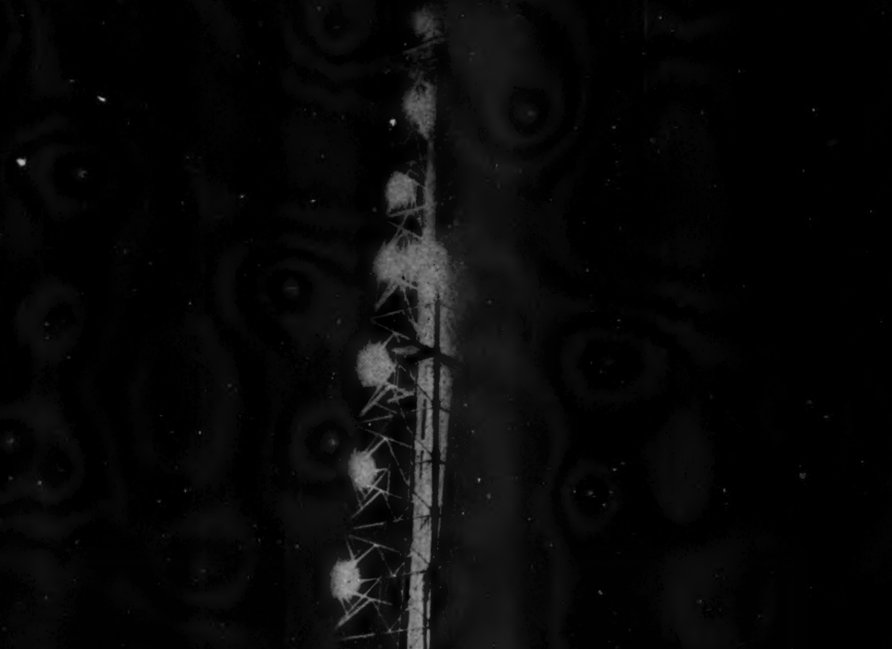
President - - - - - Robert C. Lafferty
Owens, Libbey-Owens Gas Department

Vice-President - - - J. Hawker Newlon
Philadelphia Gas Company
Pittsburgh, Pennsylvania

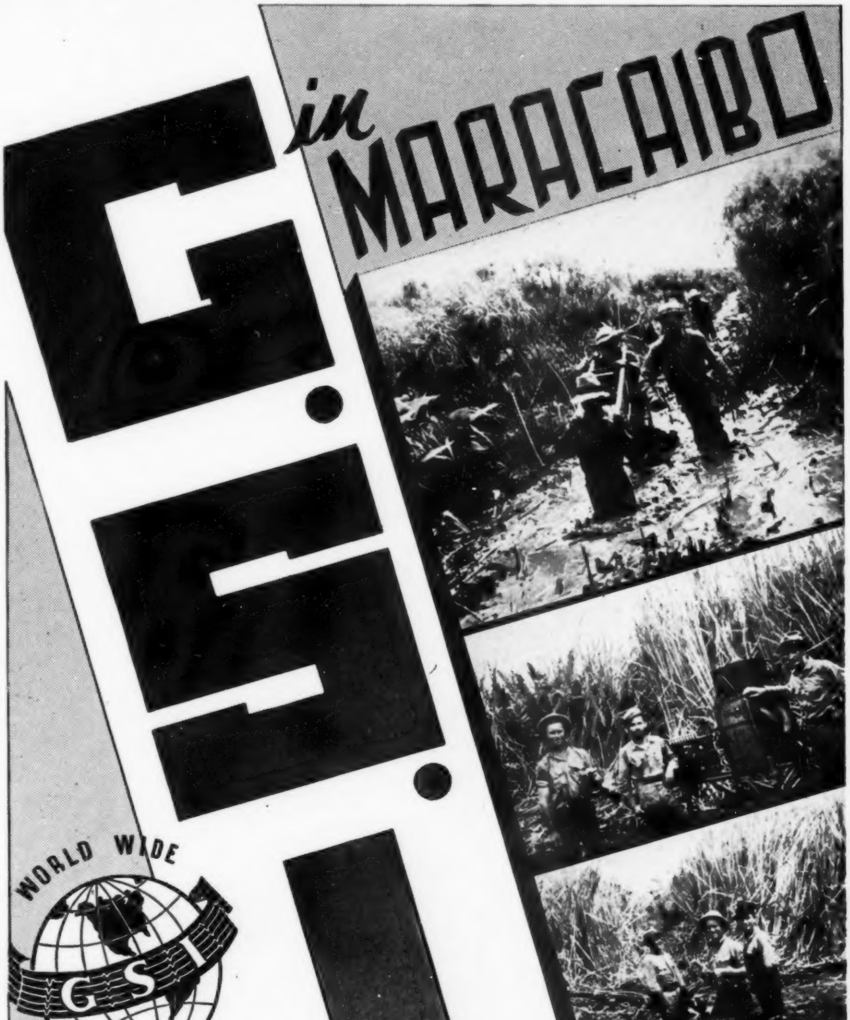
Secretary-Treasurer - - - Charles Brewer, Jr.
Godfrey L. Cabot, Inc., Box 348

Meetings: Second Monday, each month, at 6:30 P.M., Kanawha Hotel.

Schlumberger



ELECTRICAL WELL LOGGING


G.S.I.
in MARACAIBO
WORLD WIDE
G S I
EXPERIENCE
THROUGH ACHIEVEMENT YOU KNOW THIS COMPANY
GEOPHYSICAL SERVICE - INC
REFLECTION SEISMIC SURVEYS DALLAS TEXAS